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DECEMBER 1962

THE DEVELOPMENT OF A CESIUM-VAPOR-FILLED THERMIONIC ENERGY CONVERTER

FINAL TECHNICAL REPORT

PREPARED FOR

JET PROPULSION LABORATORIES
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

CONTRACT NAS-7-100
P.O. NO. 950229

PREPARED BY

RADIO CORPORATION OF AMERICA
ELECTRON TUBE DIVISION
LANCASTER, PENNSYLVANIA

AUTHORS: G.Y. EASTMAN AND D.M. ERNST

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FOREWORD

This report was prepared by the Radio Corporation of America on Contract NAS-7-100, P.O. 950229, "The Development of a Cesium-Vapor-Filled Thermionic Energy Converter". The work was administered under the direction of the Jet Propulsion Laboratories of the California Institue of Technology, Pasadena, California. Mr. Arvin Smith is Project Engineer for the Laboratories.

The report covers the work applied from 18 June 1962 through 18 November 1962 and represents the efforts of Thermionic Converter Engineering of the Electron Tube Division, RCA-Lancaster. Mr. G.Y. Eastman is the Engineering Leader responsible for the technical direction and control of the project under the direct supervision of Mr. F.G. Block, Manager. Mr. Eastman was assisted in the technical direction of the program by the following engineering personnel: R.W. Longsderff, D.M. Ernst and S.W. Kessler, Jr.

This report is the Final Technical Report and it concludes the work on the subject contract.

This report is unclassified.

ABSTRACT

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This report covers a five-month program of development, fabrication and test of cesium-vapor-filled thermionic energy converters. The units were designed for use in a solar-heated space application for the Jet Propulsion Laboratories. The geometry was limited by stringent system parameters of size and temperature.

The program was directed toward the generation of twenty-five watts of output power at an emitter temperature not exceeding 2000° Kelvin. Design objectives included a service life of one year at rated capacity at an efficiency of twenty percent.

RCA has delivered five converters designed to these requirements at operating temperature of less than 2000° Kelvin. The objectives of life and efficiency have been approached by incorporating materials and fabrication techniques which will obtain the greatest reliability and performance.

The report covers the specific techniques, procedures and geometry of the converters shipped under the contract. In addition, details of problems encountered and their solutions are explained. Test data on converters shipped is included.

Author

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THE DEVELOPMENT OF A CESIUM-VAPOR-FILLED THERMIONIC ENERGY CONVERTER

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THE DEVELOPMENT OF A CESIUM-VAPOR-FILLED THERMIONIC ENERGY CONVERTER

SECTION I

PURPOSE

RCA will design, fabricate, test and deliver to JPL five cesium-vapor-filled thermionic energy converters, in accordance with the following design requirements, design objectives, drawings/specifications and testing requirements:

A Design Requirements

(1) Electrical Power - Each converter shall deliver twenty-five watts of electrical power at rated capacity.

(2) Structural Constraint - The structural envelope shall conform with the constraints defined in JPL Drawing No. J-118977-1.

(3) Cesium Reservoir - Each converter shall be equipped with an electrically-heated cesium reservoir capable of establishing and maintaining the optimum cesium vapor pressure at any converter orientation.

(4) Radiator and Collector Heater - Each converter shall incorporate a fin-type radiator and electrical heater capable of establishing and maintaining the optimum collector temperature. The radiator shall be fabricated with excess radiative surface which can be reduced in successive increments to obtain optimum collector temperature without the aid of the electrical heater.

(5) Cavity Adapter - Four of the thermionic energy converters shall be equipped with integral emitter-cavity refractory metal adapters as detailed in JPL Drawing No. J-118977-2. One converter shall be equipped with an emitter cavity refractory metal adapter as detailed in JPL Drawing No. J-118977-3.

18 December 1962

(6) Generator Attachment Ring - Each thermionic energy converter shall be equipped with an electrically insulated generator attachment ring as detailed in JPL Drawing No. J-118977-1.

(7) All converters shall be instrumented with platinum - platinum + ten percent rhodium thermocouples as follows:

a. One as close as possible to the ceramic member of the metal-to-ceramic vacuum seal.

b. Two on the cesium reservoir as close as possible to the liquid-vapor interface.

c. Two on the collector body as close as possible to the collector surface opposite the emitter.

d. One on the radiator.

(8) The thermionic energy converters shall be capable of withstanding a minimum of twenty thermal cycles from room ambient to operating temperature. The half cycle from room ambient to operating temperature shall not require more than fifteen minutes. Cool-down will be accomplished by an abrupt termination of all heater power when the converter is at operating temperature except that the cesium reservoir heater may remain energized.

(9) The emitter temperature shall not exceed two thousand degrees Kelvin true temperature.

(10) Each converter shall be equipped with a "black-body hole" sufficiently near the emitter surface to permit an accurate pyrometer measurement of emitter true temperature.

B Design Objectives

(1) Service Life - The service life of the thermionic energy converters shall be not less than one year at rated capacity.

(2) Converter Efficiency - Converter efficiency shall be twenty percent or greater, at rated capacity.

C Drawings/Specifications

JPL Drawing Nos. J-118977-1, J-118977-2 and J-118977-3, "Solar Energy Thermionic Converter".

D Testing Requirements

(1) Minimum Electrical Testing - Each converter shall be electrically tested at operating temperature for a minimum of twenty hours prior to delivery to JPL. Converter output current and voltage, collector temperature, cesium reservoir temperature, metal-to-ceramic seal temperature, and the electrical power supplied to all heaters shall be measured continuously during the minimum electrical test period. Emitter temperature shall be measured at least three times per hour during the minimum test period.

(2) Maximum Operating Time Above Four Hundred Degrees Centigrade
The operating time per converter above 400° Centigrade shall not exceed fifty hours prior to delivery to JPL.

(3) Current-Voltage Characteristics - The current-voltage characteristics from 0.3 to 1.2 volts shall be obtained at the rated emitter temperature with optimum cesium vapor pressure and collector temperature.

SECTION II
CONVERTER DESIGN

A Introduction

RCA proposed to develop a converter operable at elevated temperatures to deliver power densities equal to the maximum obtainable of the then, current, State-of-the-Art at 2000° Kelvin. In order to accomplish this objective RCA designed a unit within specific limitations of size and geometry. The final design, as developed, is shown in Figure 1.

B Overall Converter Design

The RCA Developmental Converter A-1270, as shown in cross-section in Figure 2, was the result of compliance with the geometry and size limitations as directed by the Jet Propulsion Laboratories. This design employs four major sub-assemblies as follows: 1. Emitter; 2. Collector; 3. Cesium Reservoir; and 4. Generator Support Ring.

(1) Emitter - Tantalum was selected as the basic material for the emitter as a result of extensive evaluation of possible metals. Figure 3 shows the emitter sub-assembly and its components.

(2) Collector - The collector sub-assembly, as shown in Figure 4, employed a precise ratio of molybdenum-to-copper to obtain the correct emitter-collector spacing by means of differential expansion techniques.

(3) Cesium Reservoir - The requirements for successful operation in any orientation of the cesium reservoir, and the maintenance of the correct cesium temperature with auxiliary heaters, were met without difficulty. The details of the cesium reservoir are shown in Figure 5.

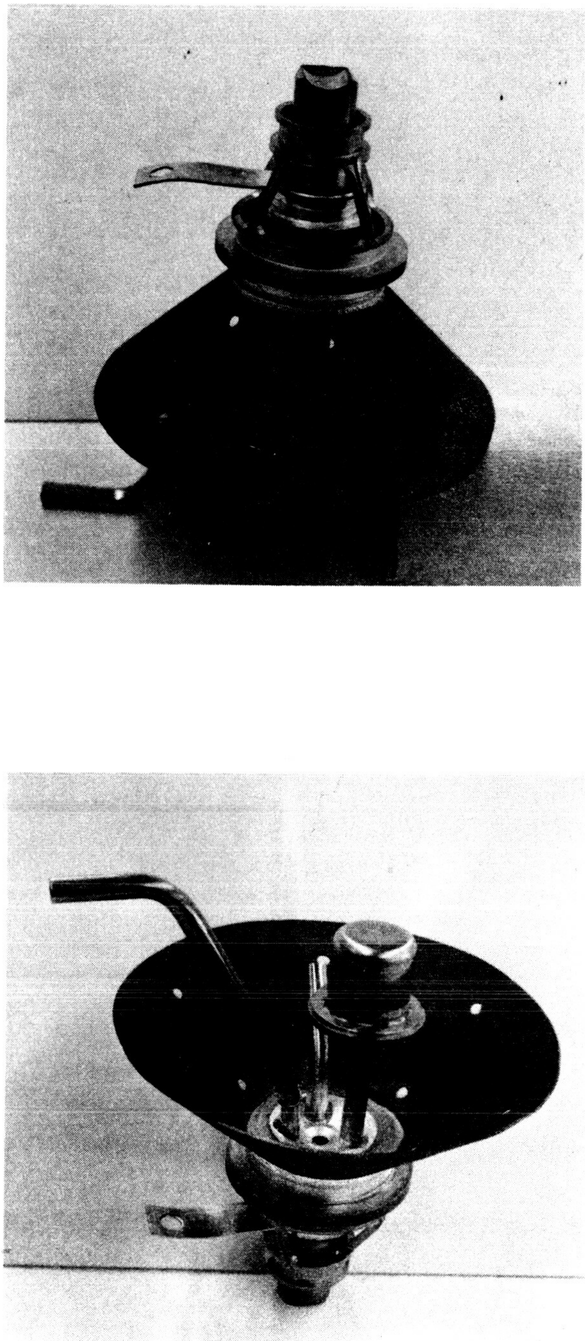


FIGURE 1 - TWO VIEWS OF THE
RCA DEVELOPMENTAL CONVERTER A-1270

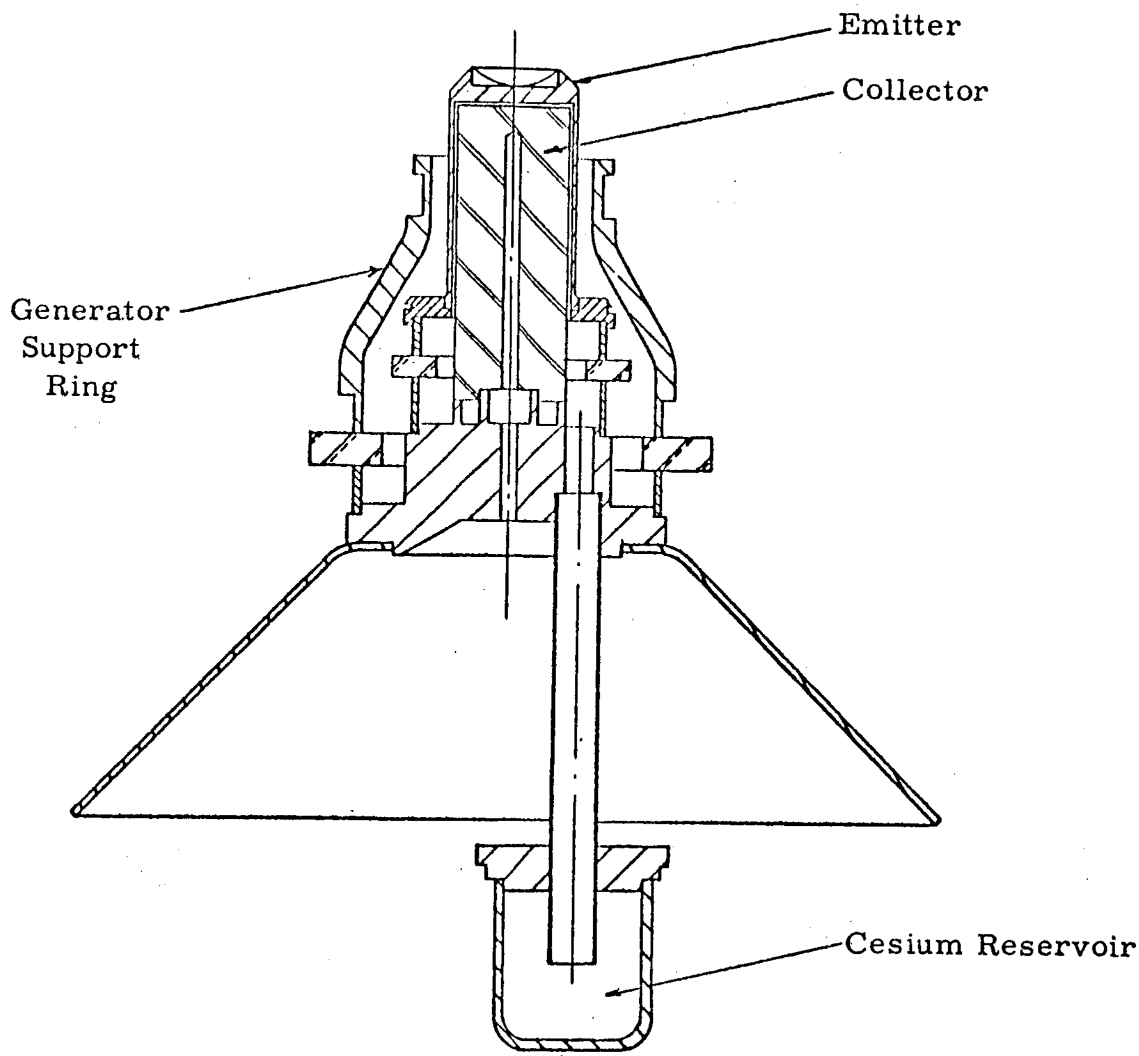


FIGURE 2 - CROSS-SECTION DRAWING OF THE RCA DEVELOPMENTAL CONVERTER A-1270

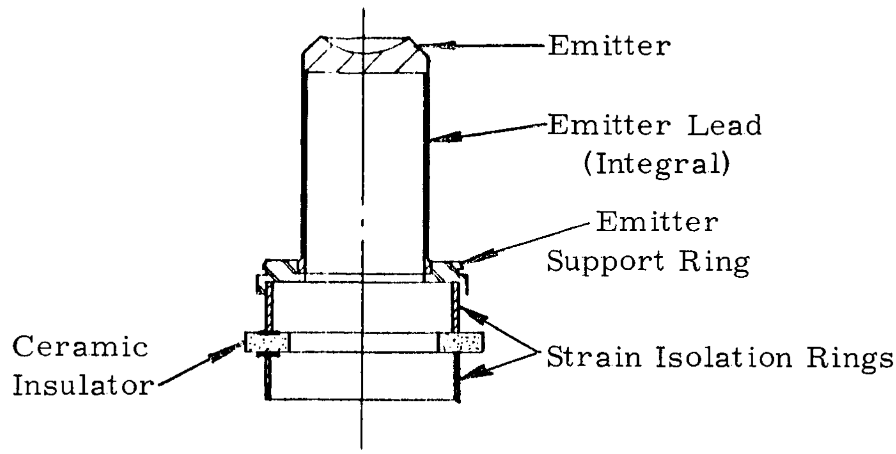


FIGURE 3 - EMITTER SUB-ASSEMBLY

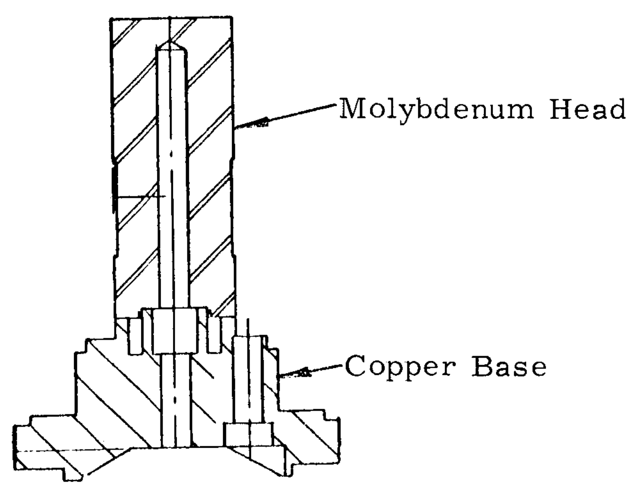


FIGURE 4 - COLLECTOR SUB-ASSEMBLY

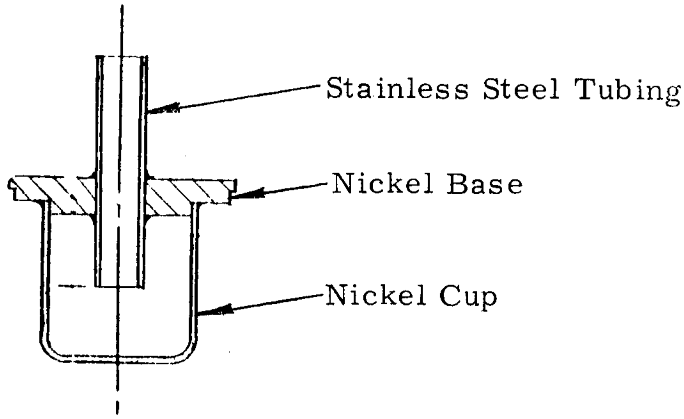


FIGURE 5 - CESIUM RESERVOIR SUB-ASSEMBLY

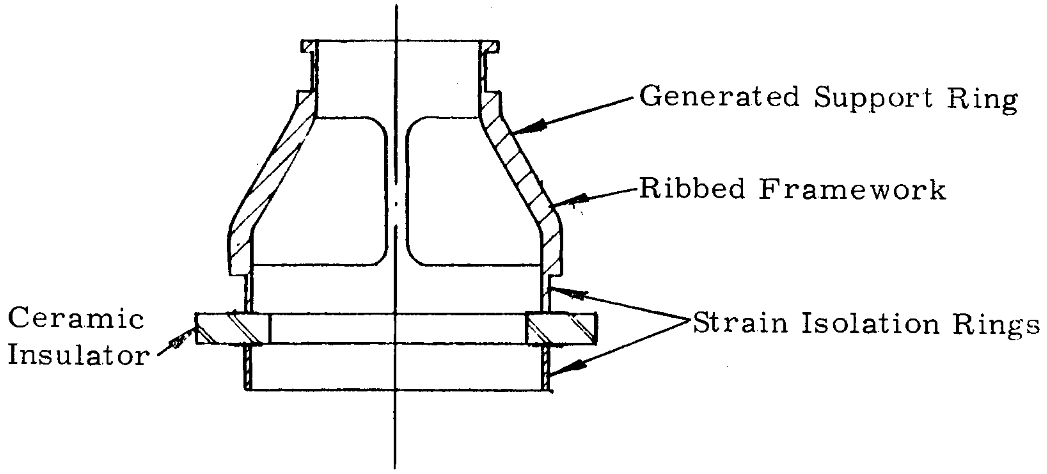


FIGURE 6 - GENERATOR SUPPORT RING SUB-ASSEMBLY

(4) Generator Support Ring - The generator support ring was isolated electrically from the converter. It was designed as a ribbed framework, as seen in Figure 6, to permit maximum open area for adequate heat radiation from the inner converter parts.

The converter was thoroughly outgassed and exhausted at temperatures above operating conditions prior to cesiation, in order to enhance life expectancy and reliability.

C Specific Converter Design

The details of the construction of the major assemblies are the results of a continuing program of refinement and modification.

(1) Emitter Subassembly - The emitter subassembly, as shown in Figure 3, consists of the one piece emitter-emitter lead, emitter support ring, ceramic insulator, and two strain isolation rings.

(a) Emitter-Emitter Lead

The emitter was fabricated from tantalum in order to utilize the low vapor pressure at the required operating temperature, to prevent the evaporation of the surface material to other internal converter components. When evaporation takes place at elevated temperatures, components are weakened by the loss of material, while those components on which the material condenses become contaminated and thus reduce operating efficiency and reliability. In an atmosphere of cesium, an emitter of tantalum demonstrates excellent thermionic emission properties.

The emitter lead was also fabricated from tantalum utilizing its favorable ratio of electrical-to-thermal conductivity and the resultant mechanical simplicity of a one piece emitter-lead structure without the need of a high-temperature joint.

However, tantalum has a limitation in that it reacts readily with carbon, nitrogen, hydrogen or oxygen at elevated temperatures. By maintaining a vacuum better than 1.5×10^{-5} torr, impurities were kept to very low levels so that this characteristic was not a limiting factor.

The one piece emitter-emitter lead was machined from tantalum rod into a cup with the required thickness on the end needed for the emitter face, and a 0.012 inch wall. The 0.012 inch wall was reduced to 0.008 inch and 0.005 inch along the lead by a rolling process. The varying wall thicknesses strengthened the lead at points of maximum stress.

The calculation of the wall thickness of the emitter lead showed that the theoretical optimum thickness was 0.004 inch. From experience, however, a minimum wall thickness of 0.005 inch was established in order to prevent failures due to crystal growth. While not necessarily leading to failure, this condition makes the structure more susceptible to stress cracking and intergranular corrosion by undesired containments in the crystal boundaries. Single crystals formed in some instances as is evident from Figure 7. However, the increased thickness prevented failure.

The emitter surface was machined according to JPL Drawing No. J-118977-2. A black body hole for optical pyrometer true-temperature readings was located in the emitter side-wall. The machined surface of the emitter was sandblasted to improve its emissivity, thereby increasing the efficiency of the emitter to absorb more thermal radiation.

The inner surface of the emitter was machined flat within 0.0005 inch, and the emitter lead was held within 0.0005 inch perpendicularity with respect to the flat surface of the emitter, thereby insuring a uniform emitter-collector spacing reference plane.

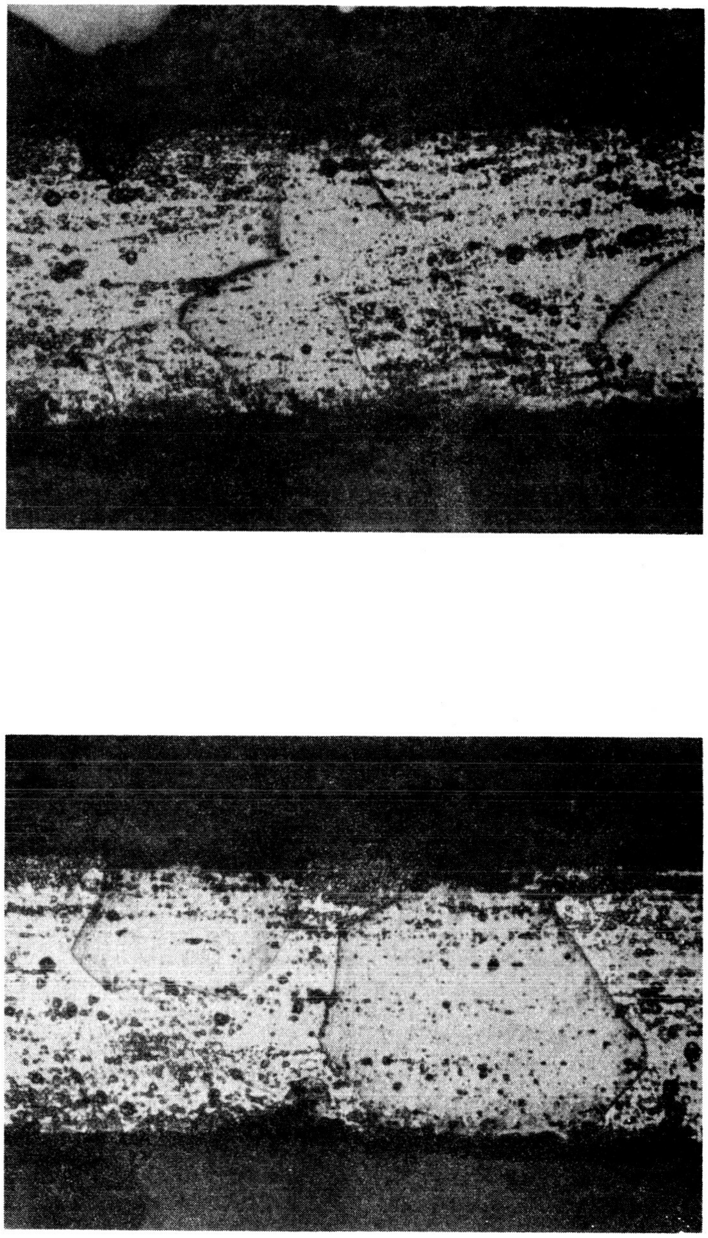


FIGURE 7 - SINGLE CRYSTAL FORMATIONS
(Tantalum 0.005 inch - Magnification X272)

(b) Emitter Support Ring

The emitter support ring was made from molybdenum because of its compatibility with cesium. Its high-thermal conductivity made it possible to distribute the thermal load uniformly around the emitter lead, minimizing temperature differences and consequent motion due to thermal expansion.

The emitter support ring was brazed to the emitter lead with zirconium as a filler, since zirconium is one of the few materials that will satisfactorily bond refractory metals.

After brazing, the emitter support ring was nickel plated taking care not to contaminate the zirconium braze area or the emitter lead with nickel, which diffuses undesirably into each of these metals at the elevated temperatures encountered during converter operation.

(c) Strain Isolation Rings

The nickel-plated, kovar, strain-isolation rings not only provided flexible members to take up the thermally-induced stresses in the ceramic-to-metal seals, but also provided low-thermal impedance paths to the ceramic. This design prevented the temperature of the ceramic from rising above a safe level during converter operation. The strain rings were nickel plated all over to prevent grain bounding penetration of the solder.

(d) Ceramic Insulator

The ceramic provides an electrical insulating portion of the vacuum envelope between the emitter and collector, so that power is not dissipated but can be utilized externally through a load.

(e) Assemblying the Emitter Subassembly

The parts were assembled on a stainless steel brazing fixture to achieve the desired parts concentricity and brazed in vacuum using copper as a filler.

(2) Collector Subassembly - The collector subassembly, as seen in Fig- 4, was the result of a calculated ratio of differential expansion to obtain the correct emitter-collector spacing during converter operation. The desired spacing was obtained by selecting the ratio of the length of material in the copper base to that of the molybdenum head to utilize the differences in thermal expansion of the collector assembly to the emitter assembly.

(a) Molybdenum Head

Sintered molybdenum was used as the head of the collector so that, in conjunction with the cesium coverage during converter operation, it would provide a very low effective work-function collector. The molybdenum served as the low expansion part of the ratio of materials needed to obtain the correct emitter-collector spacing. Because of its high melting point, the molybdenum head prevented the higher temperatures of short circuit converter operation from melting the collector and short-circuiting the converter.

(b) Copper Base

Copper was used for this component to provide the high-thermal-expansion material in the collector assembly needed to obtain the desired collector-emitter spacing. Having a high-thermal conductivity, copper also provided a low-thermal-impedance path through the collector for the unused thermal power. This characteristic aided in obtaining a minimal-area radiator fin to dispose of this power.

The copper base of the collector was machined with strain isolation lands and moats to fit matching contours machined in the molybdenum head. The lands permitted a good mechanical vacuum braze. The copper structure was sufficiently flexible to absorb the stresses applied during contraction and expansion of the joint.

Four holes were placed in the outer copper land to permit proper outgassing during the vacuum brazing of the assembly. Additional holes were added to the base to accommodate the thermocouple well, the collector lead, the cesium reservoir tubulation and the exhaust line.

The surface of the collector head was machined flat to within 0.0005 inch and perpendicular to the outside diameter of the collector base to within 0.0005 inch, to insure uniform emitter-collector spacing. The collector was then machined to the required length to complement the overall dimension of the emitter subassembly for that particular converter. The copper base of the collector and the nicoro braze area was nickel plated to prevent attack by cesium.

(3) Cesium Reservoir Subassembly - The cesium reservoir subassembly consisted of a nickel cup and base and a stainless steel tubing as shown in Figure 5.

(a) Nickel Cup and Base
Nickel was selected for this application because of its compatibility with cesium and its high-thermal conductivity. The high-conductivity insured proper temperature uniformity throughout the reservoir.

(b) Stainless Steel Tubing
Stainless steel was used to permit the desired thermal isolation from the collector to control the temperature of the cesium independently. The stainless steel tubing extended into the center of the reservoir cup so that it's open end would remain above the cesium liquid level in any orientation.

(c) Assembly

The assembly was brazed with Nicrobraze 30 in a vacuum furnace.

(4) Generator Support Ring Subassembly - The generator support ring subassembly, as shown in Figure 5, was fabricated to fulfill the purpose of the program and electrically insulated from the converter. The assembly consisted of the kovar support ring, rib and strain isolation ring as one piece, insulation ceramic and a second kovar strain-isolation ring.

(a) Insulating Ceramic

The ceramic provided electrical insulation of the converter from its support.

(b) Kovar Support Ring

The kovar provided a high-thermal-impedance path which prevented any significant thermal interaction between the converter and its supports. The ribs were so located to permit the output ceramic seal to effectively radiate its heat to space.

(c) Assembly

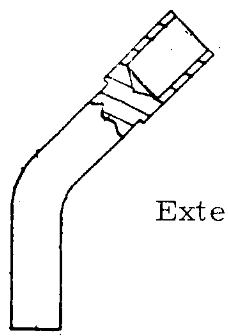
The parts were assembled on a stainless steel brazing fixture and brazed with copper solder in a hydrogen atmosphere.

(5) Converter Assembly - The four subassemblies along with the radiator fin, collector lead, exhaust line, as shown in Figure 8, and the external emitter lead were assembled and brazed with silver-copper eutectic solder in a vacuum furnace.

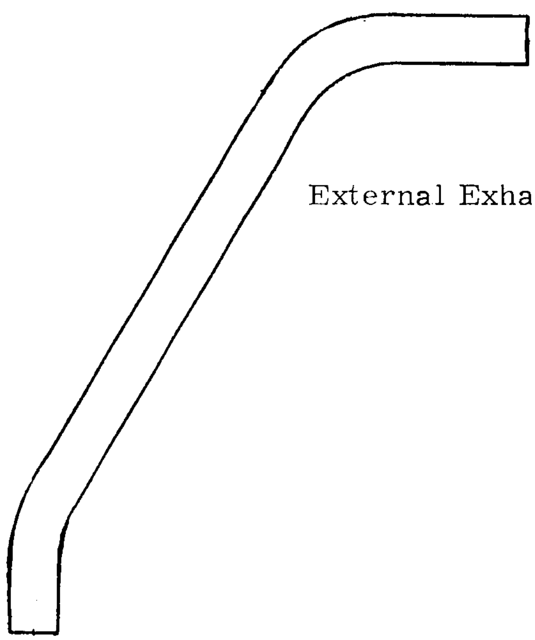
(a) Collector Lead

Copper was used for the collector lead to minimize the electrical loss between the converter and its load.

Collector Radiator Fin



External Collector Lead



External Exhaust Tubing

FIGURE 8 - ADDITIONAL PARTS OF CONVERTER ASSEMBLY

(b) Exhaust Line

The exhaust line also employed copper which is easily pinched-off with an hydraulic press to form a leak-tight, cold-weld seal. The high-thermal conductivity of copper permitted sufficient heat flow from the collector to the pinch-off to insure operation at a temperature in excess of the cesium reservoir to prevent undesired cesium condensation.

After the final braze of the converter, the exhaust tubulation was high-frequency-induction brazed to the converter with silver-copper eutectic solder. A cesium capsule was placed in the tubing and the tubing pinched-off.

(c) Collector Radiator Fin

The collector radiator fin was a one-piece copper cone designed to fit as its smaller end onto the base of the collector. The fin was treated with a silicone-aluminum[1] coating of high-thermal emissivity to obtain maximum radiation effectiveness. Holes were placed in the fin for the attachment of the fin heater.

(d) Radiation Fin Heater

The radiator fin was wrapped with a heater made from No. 22 Nichrome V wire covered with ceramic beads. Stainless steel straps bolted to the fin held the heater in place.

(e) Cesium Reservoir Heater

The cesium reservoir heater was made by wrapping beaded No. 22 Nichrome V wire around a nickel cup. Stainless steel straps spot-welded to the cup held the heater in place. This cup was then slipped over the reservoir and held in place by bending the stainless steel straps over the cesium reservoir base. The reasons for choosing a radiation type heater are as follows:

[1] U.S. Patent No. 2,891,879 assigned to Westinghouse.

1. RCA felt it important not to make the heater an integral part of the converter so that it might be easily removed and replaced.
2. By using a radiation type heater, the ultimate application of the converter is more readily demonstrated.

(6) Exhausting and Cesiation - The converter was thoroughly exhausted at elevated temperatures prior to cesiation and pinch-off from the vacuum system.

(a) Exhausting

The procedure for exhausting the converter required the use of a dual-vacuum system. One system, employing an oil diffusion pump with appropriate baffling, was used to evacuate the converter proper. The second system, also employing an oil diffusion pump with appropriate baffling, was a vacuum chamber which served to simulate the space environment outside of the converter. It thus provided protection of the converter from the atmosphere, the proper conditions for radiation of the rejected heat from the converter and for operation of the electron-bombardment heat source.

The converter was mounted in the test chamber, connected to its exhaust manifold, and pumping started. While the converter pump-down was proceeding, thermocouples were placed on the metal-to-ceramic seal, collector fin, cesium reservoir and in the collector well. The converter emitter was grounded to provide a safe return path for the electron-bombardment power. The cesium reservoir and collector fin heaters were attached to vacuum feed-throughs. The bakeout heater was attached to an electrical feed-through and placed around the exhaust tubulation, cesium capsule appendage and exhaust manifold section. The black-body hole in the emitter side wall was positioned to observe temperature through the heat shields. High voltage to ground insulation was checked as well as continuity of the radiator-fin, cesium-reservoir and bombardment heaters and the thermocouples. A glass bell jar was installed to close the chamber and pumping was started.

Both exhaust systems were pumped to a pressure of 50 microns or less and bake-out started on the "molecular sieve" high-vacuum traps. After an initial rise the pressure returned to its original level or less. The diffusion pumps were then activated. When the pressure dropped into the 10^{-4} torr range, bake-out of the exhaust manifolding and cesium line was started. After a brief pressure rise, heating of the converter to 400° Centigrade was intitiated. The entire system, including the converter, was kept at 400° Centigrade for approximately one hour. At this time, both "molecular sieve" traps were cooled to room temperature where their effectiveness in trapping hydrocarbons is high. When the traps had reached 200° Centigrade, cooling of the manifolding was started. When the "molecular sieve" traps and manifolding were cool, liquid nitrogen was applied to a trap in the converter system as a further safe-guard. The exhaust tubing and cesium appendage were maintained at 400° Centigrade and the converter temperature raised slowly until all points were at a temperature in excess of their normal operating condition. The emitter was raised to 2000° Centigrade. A maximum pressure limit of 10^{-5} torr was observed during this process. This condition was maintained for at least one hour until the pressure had dropped to a stable level. The converter was then cooled, the bell jar removed, and the converter pinched-off from the vacuum system. The pressure at pinch-off was typically 2×10^{-8} torr.

(b) Cesiation

The cesium capsule was crushed to admit cesium to the converter. The tubulation was heated to a temperature of 350° Centigrade for five minutes to drive the cesium into the converter where it condensed. The heater tape was then removed and the cesium tubulation was pinched off completing the cesiation process. The converter was then ready for test.

SECTION III

PROBLEM AREAS

A Introduction

During the course of developmental projects, the initial design is revised through a continuing program of investigation, modification and refinement. The achievement of the program objectives requires the solution of specific problems and the selection of the most effective techniques. The development of a converter for Jet Propulsion Laboratories was typical of this pattern.

B Problem Areas

Emphasis of effort was required in several areas of investigation as detailed below.

(1) Emitter Assembly Braze - The emitter lead-to-emitter support ring braze joint required the selection of a satisfactory brazing alloy.

(2) Emitter-Lead Embrittlement - The embrittlement of the tantalum emitter lead due to crystal growth and hydrocarbon attack required changes in design and processing.

(3) Collector Assembly - The braze between the copper base and the molybdenum head presented difficulties to guarantee both a vacuum-tight seal and a mechanically strong joint which would withstand the thermal expansion difference between copper and molybdenum.

By changing the design of the collector radiator fin from radial to a one-piece cone the mass of the collector was reduced and the effective radiator area increased.

(4) Cesium Reservoir - The change in the radiator fin increased the thermal power to the cesium reservoir and required a compensation to optimize the reservoir temperature.

(5) Converter Slump - After ten to fifteen hours of operation several of the converters tested slumped from the original power output.

C Specific Details of Problem Solutions

(1) Emitter Assembly Braze

(a) Problem

Considerable difficulty was encountered in the selection of a suitable brazing alloy for brazing the tantalum emitter lead to the molybdenum emitter support. Initial brazing tests using Nicrobraz 30 as the filler were partially successful. However, it was not possible in practice to prevent excessive alloying with the tantalum and resultant embrittled and leaky joints. Attempts to use pure copper as the filler were also unsuccessful because of the need to nickel plate the tantalum to obtain good wetting. The plating proved unreliable. Pure nickel, nickel-molybdenum eutectic and nickel-niobium eutectic mixtures were also unsuccessful because of an excessive alloying with the molybdenum. Figure 9 shows the intergranular cracking of the molybdenum typical of these brazes.

(b) Solution

A successful procedure was established utilizing zirconium as the brazing filler alloy. The braze was carried out at 1770° Centigrade in vacuum. The quantity of zirconium was kept to a minimum. The solution reactions, with the structural materials, were carried to completion to prevent the subsequent formation of lower melting eutectic compositions.

(c) Suggested Improvement

A further improvement will result from the substitution of electron-beam welding to eliminate entirely the necessity of filler material.

Molybdenum Support Ring

Braze Filler

Photograph taken of cracking of molybdenum near the tantalum emitter braze joint at 38.8 magnification.

FIGURE 9 - EXAMPLE OF STRESS IN MOLYBDENUM

(2) Emitter Lead Embrittlement

(a) Problem

A serious problem encountered in the fabrication process was the embrittlement of the tantalum emitter lead as shown in Figure 10. Four converters failed because of cracks and subsequent leaks from this cause. One of these was shown to be due to a water leak in the vacuum bell jar. However, analysis of the remaining three such converters showed strong evidence of hydrocarbon reaction during the exhaust cycle.

(b) Solution

The operation of the exhaust equipment was revised to prevent any hydrocarbons from reaching the tantalum while at elevated temperatures. Both internal and external vacuum systems were maintained at pressures below 10^{-4} torr throughout bake-out and below 10^{-5} torr subsequent to bake-out. The heating cycle of the "molecular sieve" traps was modified to improve their effectiveness during converter outgassing. A liquid-nitrogen trap was added to the converter pumping line as an additional barrier to the back-streaming of diffusion pump oil vapor.

The analysis showed that the cracking of the emitter lead wall was confined to the more hightly stressed points directly above the joint to the support ring. To improve reliability without degrading converter performance, the emitter lead wall was increased in this area and reduced to the 0.005 inch wall in steps as shown in Figure 11.

No further incidence of this problem occurred. The action taken appears adequate.

(3) Collector

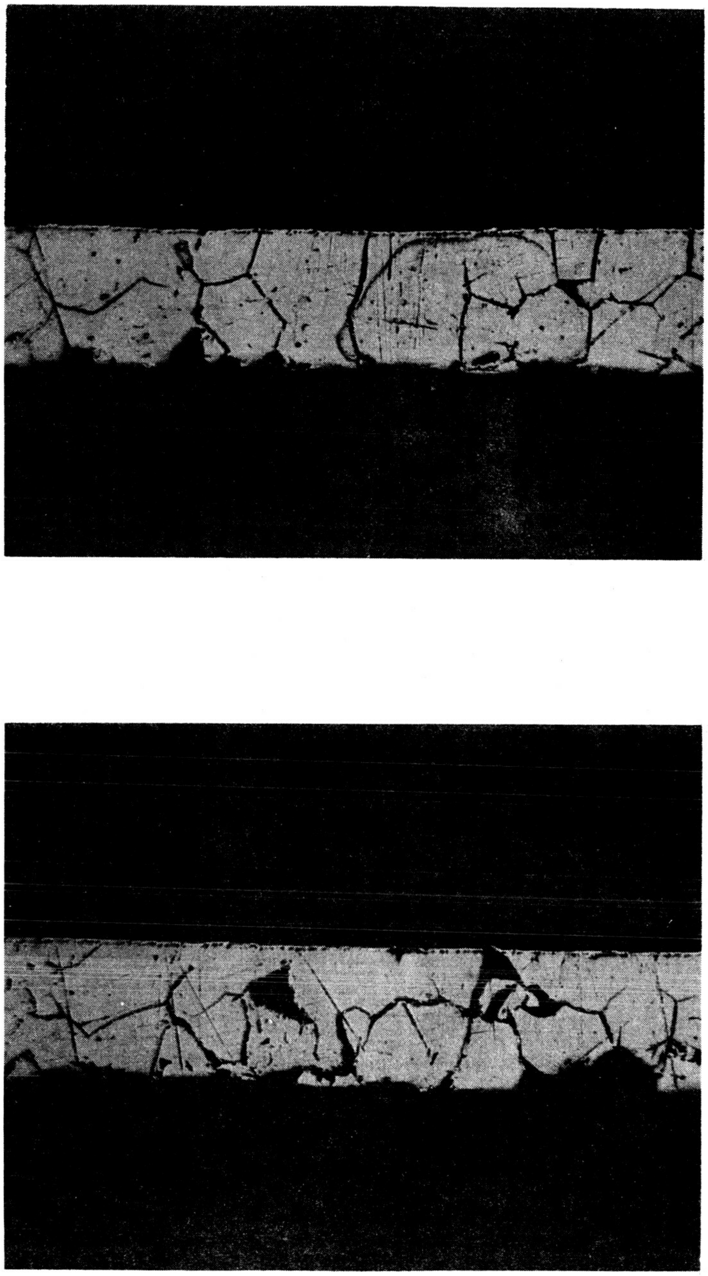


FIGURE 10 - TWO EXAMPLES OF HYDROCARBON ATTACK ON TANTALUM EMITTER WALL

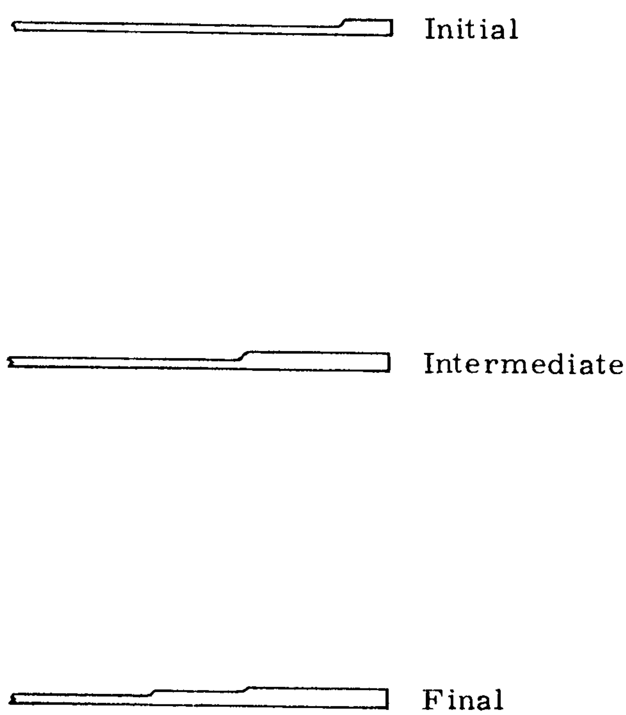


FIGURE 11 - EVOLUTION OF EMITTER LEAD

(a) Problem

The initial collector braze between the molybdenum head and the copper base was unsatisfactory. Tests were made using Nicro-braz 130, and a nickel tubing as shown in the cross-section of Figure 12. However, in actual converter construction consistent difficulty was encountered in obtaining vacuum-tight joints. Poor braze quality and separation of the parts due to expansion of the nickel were both shown to exist.

(b) Solution

The nickel tubing was removed. The molybdenum head was machined so lands in the copper base would partially fit into the molybdenum moat leaving a small area for the braze to fill (Figure 13). Tight tolerances were held so the thermal expansion would help make the braze. Nicoro was substitured for the Nicro-braz.

(c) Suggested Improvement

The substitution of a one piece, all copper collector, is proposed eliminating the joint under discussion. Added benefits would improve converter weight as described below.

(4) Rejection of Collector Heat

(a) Problem

Tests of the first converter showed that the heat rejection characteristics of the radiator were marginal.

(b) Solution

By reducing the length of the thermal path in the collector and incorporating a conical, one-piece fin the efficiency of the radiator was increased. A worthwhile reduction in mass also resulted. The radiator emissivity was improved with the addition of a black

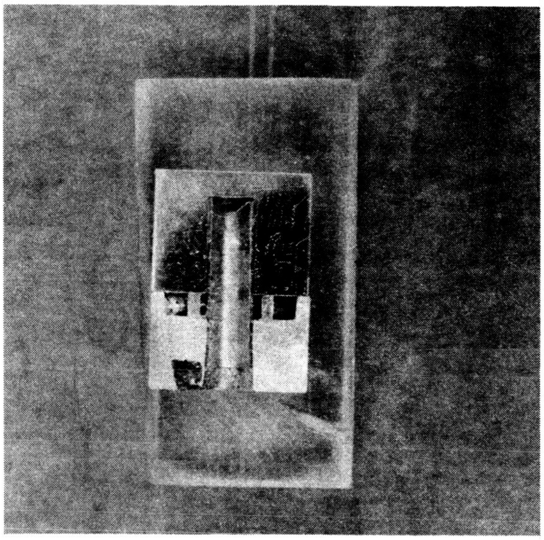


FIGURE 12 - INITIAL COLLECTOR BRAZE

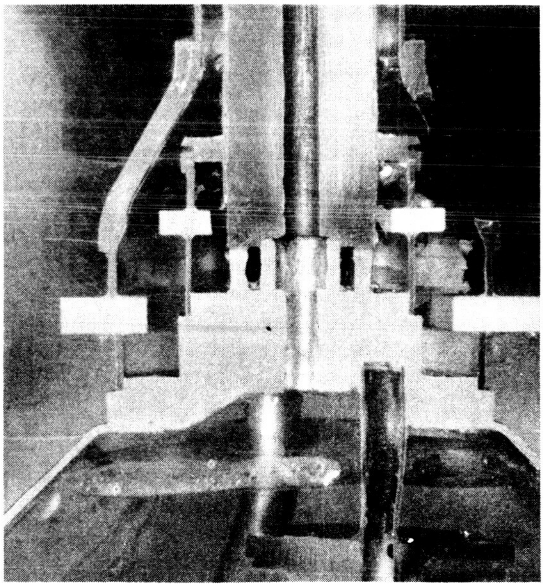


FIGURE 13 - FINAL COLLECTOR BRAZE

coating. Aquadag was used at first, but was replaced in later converters with a more adherent, stable, silicone-aluminum coating.

(c) Suggested Improvement

A substantial increase in radiator effectiveness and reduction in converter weight would result from the use of an all copper collector.

(5) Cesium Reservoir Assembly

(a) Problem

The equilibrium temperature of the cesium reservoir in the first converter was somewhat higher than desired, and limited test flexibility particularly at high collector and radiator temperatures.

(b) Solution

A shield was designed to protect the cesium reservoir from radiated heat. This modification together with the revised fin design resulted in the desired operating condition which required heater power to maintain correct reservoir temperature at all times.

(c) Suggested Improvement

The current solution is considered adequate.

(6) Degradation of Converter Performance

(a) Problem

The slumping of converter power output after several hours operation was a serious problem. Of the seven converters which were operated for the twenty hour period, four slumped. In one case a vacuum leak was shown to be the cause. The remaining three were very similar in behavior. After initially producing approximately 24 watts of power output, the converters operated ten to fifteen hours at a relatively constant level and then began to deteriorate. During this slumping period the output dropped to approximately 15 watts while the emitter temperature remained unchanged and the collector temperature rose while the power input was maintained at an approximately constant level. It was noted that in at least one case the deterioration was proportionally greater at the high-current end of the volt ampere curve than at the high-voltage end. It is felt that different ionization mechanisms may prevail at these points: the "Ball-of-Fire" arc mode in the high-current region and the contact ionization mode in the high-voltage region. If a difference in effect does exist between the modes, the cause may well lie in the plasma, since a change in work function would affect the two modes similarly.

It has been shown in previous work at RCA that the presence of certain gases can interfere with the photon trapping essential to the "Ball-of-Fire" operation and cause slumping. The presence of such a gas could also account for the increased heat transfer between emitter and collector as described.

(b) Solution

Several steps were taken to alleviate the problem. Higher temperatures were used during the original firing of the parts and during exhaust the temperature at which the converter parts were processed was higher than any during converter operation.

(c) Suggested Improvement

Higher exhaust processing temperatures should be employed for even longer periods of time. A cesium "still" should be introduced during the exhaust process to allow actual converter operation while removing any gases released. Mass spectrometer measurements should be carried out to determine the identity of gases released in the converter. Converters which show slumping output should be opened, re-exhausted and recesiated. Many converters thus reprocessed at RCA have shown marked improvement. Materials, such as tantalum, which are likely to getter and give up gases as temperatures change should be avoided where possible.

SECTION IV
TEST DATA

A Introduction

After exhaust and cesiation, the converter was tested in the same vacuum chamber used for exhaust. The converter was optimized at a load point and a D. C. load curve was taken from 0. 3 volts to 1. 2 volts. The output of the converter was reoptimized and the twenty hours life test started.

The test data presented covers the information observed from the five converters shipped to JPL and two additional converters of initially high power output in which degradation was seen.

B Overall Test Procedures and Data

(1) Preparation for Converter Test

(a) Preliminary

The converter was set-up in the vacuum chamber, as seen in Figure 14, being held in place by a base plate and three clamps, as seen in Figure 15. Thermocouples and leads were checked and the system was evacuated.

(b) Warm Up of the Converter

When the pressure in the environmental system was in the 10^{-5} torr range, the converter was gradually heated and the optimum cesium reservoir collector temperatures determined.

(2) Load Curve

After the converter was optimized, a D. C. load curve from 0. 3 to 1. 2 volts was taken.

(3) History of the Converters

The construction, relating to material and ~~brazing~~ brazalloys, output data

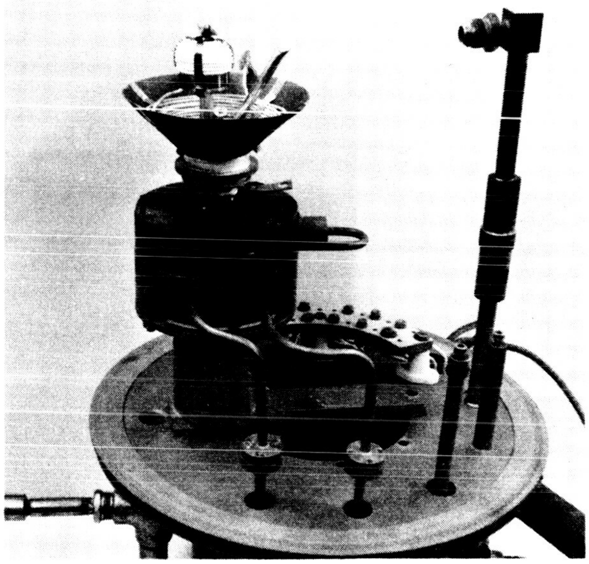


FIGURE 14 - CONVERTER BEING PREPARED FOR TEST

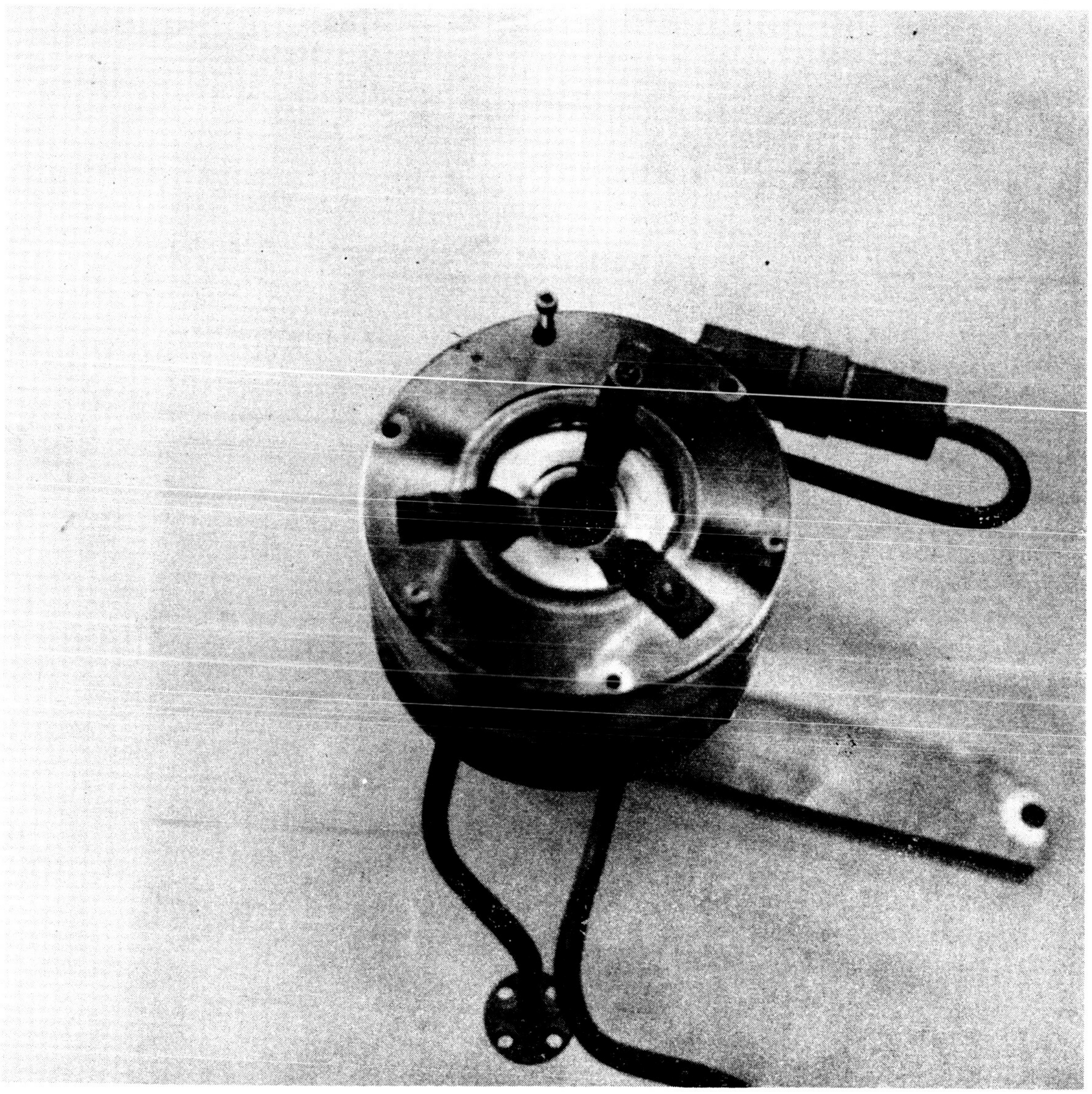


FIGURE 15 - CONVERTER SUPPORT ASSEMBLY

and final conditions of the eighteen converters fabricated for the subject program will be detailed.

(4) Test Data

The output characteristic of seven pertinent converters had been prepared in detail.

C Specific Testing of Converters

(1) Set-Up of Converter

The converter was tested in the same vacuum environment used for exhaust procedures as shown in Figure 14. It was held in place by three stainless steel fingers clamping the generator support ring to a stainless steel baseplate, as seen in Figure 15. The baseplate was made variable in its vertical position so the outer surface of the emitter could be positioned as desired with respect to the electron bombardment heater.

The six thermocouples and the leads to the cesium reservoir and fin heaters were then placed on the converter and spot welded to the feedthroughs. The voltage and current leads were connected to the converter with the emitter grounded to provide a safe return for the electron bombardment power.

The black body hole in the emitter was aligned with holes in the heat shields around the heater. The high-voltage leads were inspected for shorts to ground. The continuity of the thermocouples and heaters was verified.

(2) Warm-Up of Converter

The environmental system was evacuated to a pressure in the 10^{-5} torr range which was maintained throughout the testing period. At that vacuum, the electron bombardment filamentary heater (thoriated tungsten) was energized. When the temperature of the heater reached 2000° Kelvin, the high voltage was applied and heating of the converter emitter started. At the same time, a current of approximately three amperes was passed through the cesium reservoir heater.

The emitter temperature was raised by increasing the bombardment power until all temperatures were sufficient to produce an open circuit voltage of 2.5 volts. The converter was then connected to a variable electrical load set at approximately the optimum value.

The emitter was then heated to an equilibrium temperature of approximately 1700° Centigrade, off-setting the rising electron cooling of the emitter with increased bombardment power.

From this point, the cesium reservoir temperature was varied up and down until an optimum pressure was determined. The load was then varied to find the optimum load point keeping the cesium pressure constant. When the optimum load was found, the cesium pressure was again optimized.

(3) Load Curve

The load curve was then taken by varying the load from optimum to open circuit condition and back to optimum load. The emitter temperature was maintained constant by adjusting the bombardment heater power. Then the load was decreased to the short circuit condition. The emitter temperature was not allowed to drop below 1700° Centigrade during this operation at low load resistance in order to insure against accidental contact with the collector as it expanded due to its increased thermal dissipation. Pertinent data are presented in Table I through VI for pertinent converters at three load points on the load curve.

TABLE I

TEST DATA SHEET FOR RCA CONVERTER A-1270

SERIAL NUMBER 6

Temperatures	Open Circuit		Optimum		Short Circuit	
Temitter	1700° C		1695° C		1700° C	
Tcollector	637° C		765° C		820° C	
Tcesium reservoir	265° C		340° C		385° C	
Tceramic seal	400° C		460° C		435° C	
Tfin	310° C		425° C		350° C	
Input Power						
E_f	7.0	volts	6.95	volts	7.0	volts
I_f	35.0	amps	34.5	amps	35.0	amps
E_b	950.0	volts	1000.0	volts	1125.0	volts
I_b	0.26	amp	0.31	amp	0.32	amp
I_{cs}	2.7	amps	3.0	amps	2.9	amps
Output						
E_o	1.35	volts	0.66	volts	0.28	volts
I_o	2.5	amps	34.0	amps	70.0	amps
P_o	3.3	watts	22.5	watts	19.6	watts

TABLE II

TEST DATA SHEET FOR RCA CONVERTER A-1270

SERIAL NUMBER 11

Temperatures	Open Circuit	Optimum	Short Circuit
Temitter	1705° C	1720° C	1710° C
Tcollector	543° C	675° C	733° C
Tcesium Reservoir	370° C	378° C	379° C
Tceramic Seal	400° C	435° C	429° C
Tfin	310° C	346° C	345° C

Input Power						
E_f	8. 1	volts	8. 1	volts	8. 1	volts
I_f	37. 0	amps	37. 0	amps	37. 0	amps
E_b	760. 0	volts	830. 0	volts	880. 0	volts
I_b	0. 28	amps	0. 32	amps	0. 35	amps
I_{cs}	3. 0	amps	3. 0	amps	2. 8	amps

Output						
E_o	1. 2	volts	0. 52	volts	0. 23	volts
I_o	2. 5	amps	21. 5	amps	45. 5	amps
P_o	3. 0	watts	11. 2	watts	10. 4	watts

TABLE III

TEST DATA SHEET FOR RCA CONVERTER A-1270

SERIAL NUMBER 12

Temperatures	Open Circuit	Optimum	Short Circuit
Temitter	1707° C	1720° C	1710° C
Tcollector	605° C	795° C	835° C
Tcesium reservoir	384° C	400° C	392° C
Tceramic seal	410° C	485° C	460° C
Tfin	390° C	435° C	435° C

Input Power

E_f	7.0	volts	7.0	volts	7.0	volts
I_f	34.0	amps	34.0	amps	34.0	amps
E_b	760.0	volts	940.0	volts	940.0	volts
I_b	0.28	amps	0.35	amps	0.36	amps
I_{cs}	2.9	amps	3.0	amps	2.9	amps

Output

E_o	1.20	volts	0.49	volts	0.33	volts
I_o	5.2	amps	48.8	amps	62.0	amps
P_o	6.3	watts	23.9	watts	20.4	watts

TABLE IV

TEST DATA SHEET FOR RCA CONVERTER A-1270

SERIAL NUMBER 14

Temperatures	Open Circuit		Optimum		Short Circuit	
$T_{emitter}$	1715° C		1711° C		1700° C	
$T_{collector}$	598° C		805° C		930° C	
$T_{cesium\ reservoir}$	387° C		390° C		390° C	
$T_{ceramic\ seal}$	427° C		470° C		480° C	
T_{fin}	330° C		365° C		375° C	
Input Power						
E_f	7.7	volts	7.6	volts	7.7	volts
I_f	35.0	amps	35.5	amps	35.5	amps
E_b	920.0	volts	1030.0	volts	1070.0	volts
I_b	0.25	amps	0.30	amps	0.31	amps
I_{cs}	3.0	amps	3.1	amps	3.0	amps
Output						
E_o	1.2	volts	0.68	volts	0.35	volts
I_o	7.0	amps	35.0	amps	55.0	amps
P_o	8.4	watts	23.8	watts	19.3	watts

TABLE V

TEST DATA SHEET FOR RCA CONVERTER A-1270

SERIAL NUMBER 15

Temperatures	Open Circuit	Optimum	Short Circuit
Temitter	1700° C	1720° C	1710° C
Tcollector	545° C	790° C	830° C
Tcesium reservoir	388° C	390° C	405° C
Tceramic seal	415° C	470° C	470° C
Tfin	310° C	355° C	355° C

Input Power						
E_f	7.6	volts	7.6	volts	7.6	volts
I_f	35.0	amps	35.0	amps	35.0	amps
E_b	890.0	volts	1100.0	volts	1120.0	volts
I_b	0.25	amps	0.30	amps	0.35	amps
I_{cs}	3.2	amps	3.0	amps	3.2	amps

Output						
E_o	1.20	volts	0.61	volts	0.38	volts
I_o	5.0	amps	40.0	amps	62.0	amps
P_o	6.0	watts	24.4	watts	23.5	watts

TABLE VI

TEST DATA SHEET FOR RCA CONVERTER A-1270

SERIAL NUMBER 16

Temperatures	Open Circuit		Optimum		Short Circuit	
Temitter	1725° C		1720° C		1725° C	
Tcollector	600° C		820° C		820° C	
Tcesium reservoir	385° C		395° C		390° C	
Tceramic seal	420° C		470° C		515° C	
Tfin	300° C		330° C		350° C	
Input Power						
E_f	7.7	volts	7.7	volts	7.7	volts
I_f	35.0	amps	35.0	amps	35.0	amps
E_b	1000.0	volts	1160.0	volts	1190.0	volts
I_b	0.245	amps	0.290	amps	0.310	amps
I_{cs}	2.9	amps	3.0	amps	2.7	amps
Output						
E_o	1.18	volts	0.65	volts	0.35	volts
I_o	8.5	amps	43.0	amps	58.5	amps
P_o	10.0	watts	28.0	watts	20.4	watts

(4) Converter Histories

The final converter design had an effective emitter area of 2.07 square centimeters and an emitter-collector spacing of approximately 0.002 inch. The emitter-collector spacing was determined for the optimum operating conditions. Variation in output current resulted in a change in collector temperature and changed the spacing. The spacing was obtained by the difference in the differential expansion of the emitter and collector. In short circuit operation the spacing was greater than optimum.

(a) Standardized Construction Techniques

The ceramic seal braze of the emitter employed copper as a standard filler.

The copper collector base and Nicoro braze joints were nickel plated.

The generator support ring sub-assembly was brazed with copper and the cesium reservoir assembly was brazed with Nicrobraz 30.

The first four converters were constructed with a very large copper collector base and radial radiator fins. The remaining converters had a much smaller collector base and a one-piece cone-shaped radiator fin. All of the fins were hydroblasted to raise their emissivity and converters, Serial Numbers 11 and 12, had a coating of Aquadag sprayed on the fin to improve its emissivity. The Aquadag often peeled during testing. The remaining converters were treated with a high-emissivity silicone-aluminum coating. Unless otherwise noted, the power output figures given were obtained at emitter temperatures of slightly less than 2000° Kelvin.

(b) Specific Construction Details

Each converter incorporated certain individual construction details which are itemized below and referenced to converter serial numbers:

(1) The tantalum emitter was brazed to the molybdenum support with Nicrobraz 30. The converter leaked after brazing. The leak was sealed with copper. The collector assembly employed nickel tubing and Nicrobraz 130 as described in Section III, above. This assembly also leaked. The overall converter assembly was continued however in order to obtain fabrication, spacing and temperature distribution information.

Final converter was brazed with Nicrobraz. The converter was used for spacing tests between emitter and collector. No definite spacing was determined with the cathetometer. The unit was electrically shorted at all times and therefore scrapped.

(2) The tantalum emitter was brazed to the molybdenum support with Nicrobraz 30. The joint leaked. The leak was sealed with copper during ceramic seal braze.

The molybdenum head-to-copper base junction, employing nickel tubing, was brazed with Nicrobraz 130. The molybdenum head was nickel plated. The collector was damaged and brazed area leaked. The assembly was completed to gain further information.

The final converter was brazed with Nicrobraz L. M. The converter was used for spacing tests. Spacings of 0.002 inch to 0.008 inch between emitter and collector, depending on electrode temperatures, was observed with a cathetometer. The converter was scrapped.

(3) The tantalum emitter was brazed to the molybdenum support with copper.

The molybdenum head was brazed to the copper base employing nickel tubing and using Nicoro. The molybdenum was also nickel plated.

The converter assembly was brazed with silver-copper eutectic solder. The emitter-collector spacing was approximately 0.003 inch under optimum operating conditions. The output was 5.2 watts at 0.41 volt and 12.7 amperes. The collector shorted to the emitter after five hours of operation. Analysis showed nickel deposits on the tantalum emitter. The converter was scrapped.

(4) The tantalum emitter was brazed to the molybdenum support with copper. The junction leaked. The leak was sealed with Nicoro brazing material.

The molybdenum head was brazed to the copper base employing nickel tubing with Nicoro.

The final converter assembly was brazed with silver-copper eutectic solder.

The emitter-collector spacing was approximately 0.005 inch at operating conditions. The output was 10.5 watts at 0.92 volt and 11.5 amperes. An output of 19.7 watts was achieved at an emitter temperature of 1850° Centigrade. The unit is in storage after 25 hours of test.

(5) The tantalum emitter was brazed to the molybdenum support using copper as a filler.

The molybdenum collector was brazed to the copper base employing nickel tubing with Nicoro.

The final converter was brazed with silver-copper eutectic solder. The unit leaked on exhaust at the copper braze in the emitter sub-assembly. The converter was analyzed and then scrapped.

(6) The tantalum emitter was brazed to the molybdenum support with nickel-molybdenum eutectic solder.

The molybdenum head of the collector was brazed to the copper base employing nickel tubing and using Nicoro.

The final converter was brazed with silver-copper eutectic solder. The emitter collector spacing was approximately 0.002 inch at operating conditions. The output was 22.5 watts at 0.66 volt and 34 amperes. An output of 25.9 watts at 0.7 volt and 37 amperes was achieved at an emitter temperature of 1750° Centigrade. After twenty-one hours of test, the unit was shipped.

The remaining twelve converters had the same type of collector braze. The nickel tubing was eliminated and an additional moat was machined in the molybdenum head to give a better seal when brazed with Nicoro.

(7) The tantalum emitter was brazed to the molybdenum support with copper.

The final converter was brazed with silver-copper eutectic solder. The emitter lead was damaged on exhaust. The converter was scrapped after analysis.

(8) The Fansteel 60 emitter was brazed to the molybdenum support with copper.

The final converter was brazed with silver-copper eutectic solder. The emitter lead was damaged on exhaust. The converter was scrapped after analysis.

(9) The tantalum emitter was brazed with zirconium.

The final converter was brazed with silver-copper eutectic solder. The spacing was approximately 0.002 inch under operating conditions. An output of 13.9 watts was obtained at 0.59 volt and 23 amperes. The emitter lead became embrittled and leaked after five hours operation due to external hydrocarbon attack of the emitter lead. The converter was scrapped after analysis.

(10) The tantalum emitter was brazed with zirconium.

The final converter was brazed with silver-copper eutectic solder. The spacing was approximately 0.002 inch under operating conditions. An output of 18.7 watts was obtained at 0.58 volt and 32.5 amperes. The emitter lead became embrittled and leaked after four hours of operation due to internal hydrocarbon attack of emitter lead. The converter was scrapped after analysis.

(11) The 0.012 inch thick wall at the base of the tantalum emitter lead was extended from 0.060 inch to 0.125 inch length and brazed with zirconium.

The final converter was brazed with silver-copper eutectic solder. The spacing was approximately 0.002 inch under operating conditions. An output of 20.4 watts was obtained at 0.68 volt and 30 amperes. The output slumped after fifteen hours of operation. The converter was shipped after twenty hours of operation.

(12) The tantalum emitter lead of 0.012 inch was further extended and the thickness of 0.008 inch for 0.125 inch was maintained before the 0.005 inch wall was fabricated.

The emitter-support ring was made with zirconium. The final converter was brazed with silver-copper eutectic solder. The spacing was approximately 0.0015 inch under operating conditions. An output of 23.9 watts was obtained at 0.49 volt and 48.75 amperes. The unit was tested for twenty-five hours and then shipped.

Converter Serial Number 12 was the only unit built with the flat emitter surface, JPL Drawing Number 111977-3. The final six converters were assembled in the same manner as Serial Number 12, except as noted below.

(13) The spacing was approximately 0.002 inch. An output of 24.6 watts was obtained at 0.625 volt and 39.6 amperes. The converter slumped after twenty hours of operation. In the process of recesiation, a collector leak developed. The converter was scrapped.

(14) The spacing was approximately 0.002 inch. An output of 23.6 watts was obtained at 0.67 volt and 35 amperes. After a twenty-five hour test, the converter was shipped.

(15) The spacing was approximately 0.002 inch. An output of 24.4 watts was obtained at 0.61 volt and 40 amperes. An output of 25.2 watts was achieved at an emitter temperature of 1735° Centigrade. The unit then slumped to 14 watts. However, the converter was shipped after twenty-two hours of testing.

(16) The spacing was approximately 0.002 inch. An output of 28 watts was obtained at 0.65 volt and 43 amperes. The converter slumped to 16 watts after twenty hours. The original copper braze of the ceramic leaked and was sealed with silver-copper eutectic solder during final converter braze. The converter was decesiated and re-exhausted, but during re-exhaust a leak developed at the ceramic seal. The converter was scrapped.

(5) Test Data

Converters, Serial Numbers 6 and 11 through 16, were tested. Data were compiled into volt-ampere and volt-power curves.

In addition to the standard meters for observing voltage and power, the temperature was closely controlled and monitored.

The electron-bombardment heater, as detailed on print 344-14078, was shielded to improve the heat transfer to the emitter. The spacing between the heater and the face of the emitter varied between 0.150 inch and 0.200 inch. Optical pyrometers (Leeds & Northrup, Catalogue No. 8622-C) were checked against standards and the correction applied in use. The temperature correction for reading through the bell jar was measured and found to be approximately 15° at 1700° Centigrade. This correction was also applied in determining true operating temperatures.

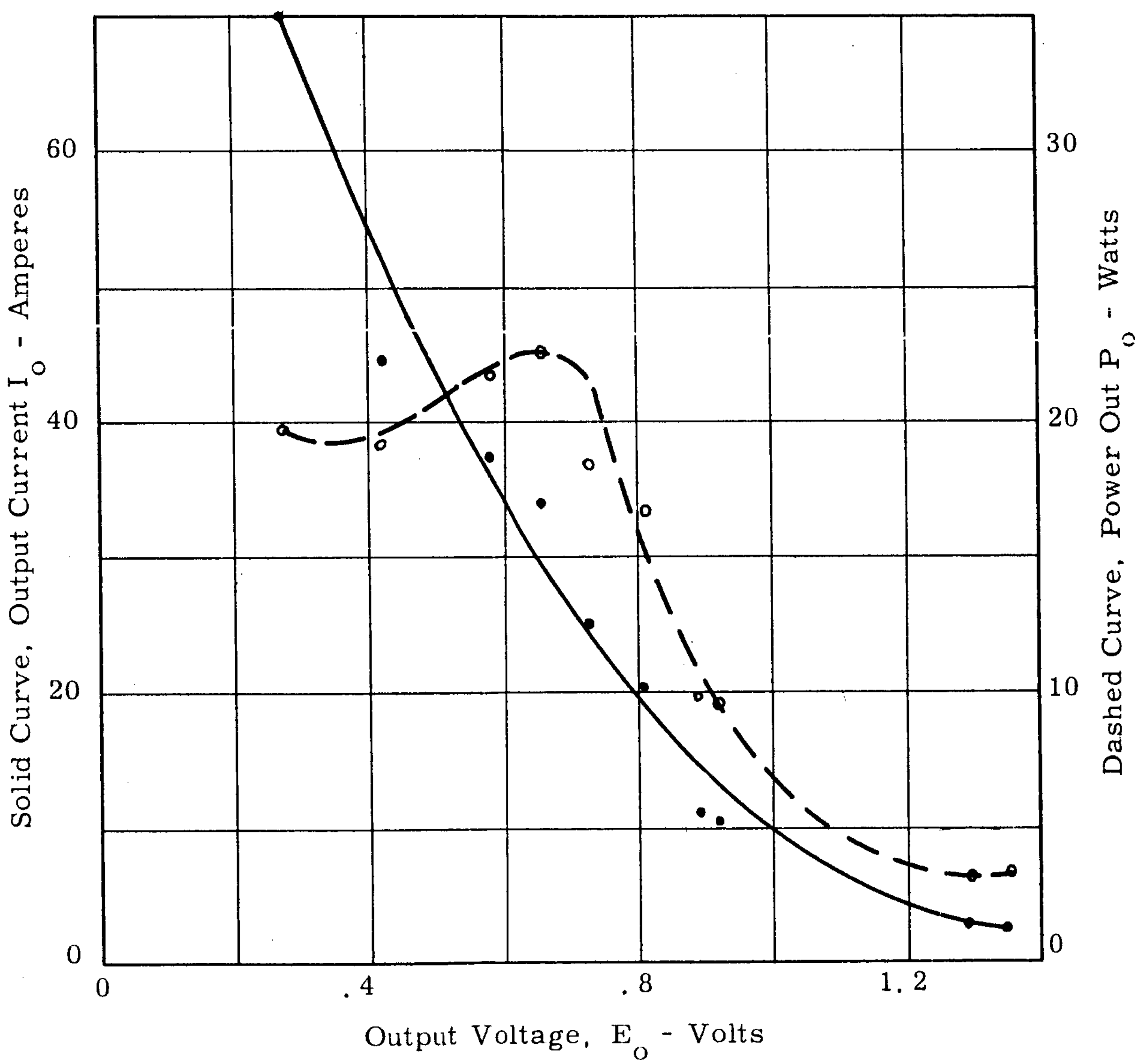
The continuous temperature of the emitter was observed with a radiation pyrometer (Radiation Electronics Company Type Thermodot, Model TD-6, Radiation Thermometer).

The data obtained from the thermocouples and the cesium reservoir and collector heaters together with voltage output, current output and emitter temperature were continuously recorded with a Honeywell-Brown Electronic Recorder (Model No. Y153X89-(C)-II-W7-16).

Operating Conditions	
$T_{emitter}$	1715°C
$T_{collector}$	750°C
T_{cesium}	375°C

Test Data

E_o - Volts	I_o - Amps	P_o - Watts
0.28	70.0	19.6
0.42	44.5	19.1
0.58	37.2	21.6
0.66	34.0	22.5
0.73	25.0	18.3
0.81	20.5	16.6
0.89	11.2	10.0
0.92	10.5	9.7
1.28	2.5	3.2
1.35	2.5	3.3

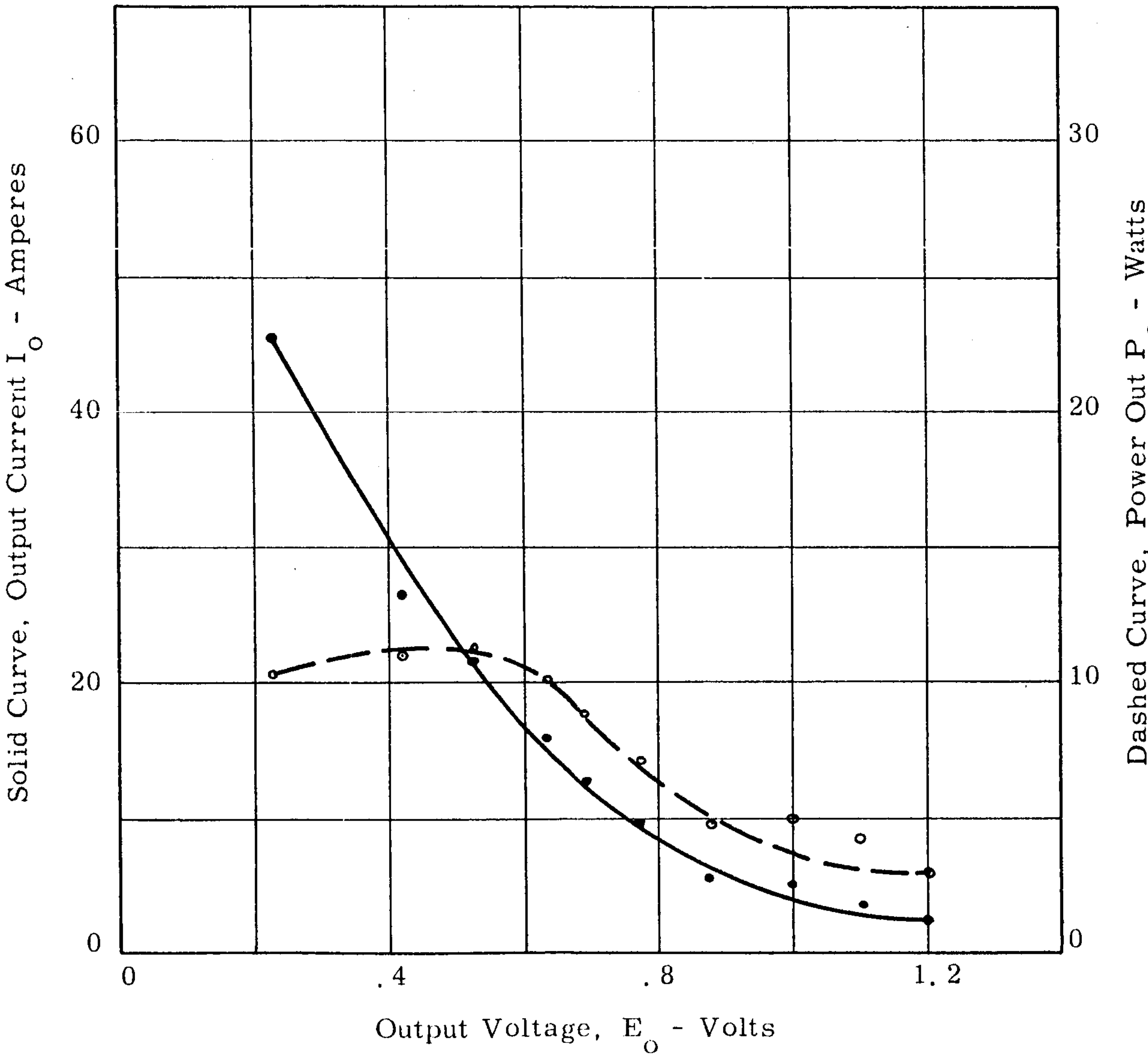


VOLT-AMPERE CURVE, VOLT-POWER CURVE
THERMIONIC CONVERTER
TYPE A-1270, SERIAL NUMBER 6

Operating Conditions	
$T_{emitter}$	1715°C
$T_{collector}$	650°C
T_{cesium}	375°C

Test Data

E_o - Volts	I_o - Amps	P_o - Watts
0. 23	45. 5	10. 4
0. 42	26. 5	11. 1
0. 52	21. 5	11. 2
0. 63	16. 0	10. 1
0. 69	13. 0	9. 0
0. 77	9. 5	7. 3
0. 87	5. 5	4. 8
1. 00	5. 0	4. 5
1. 10	3. 8	4. 2
1. 20	2. 5	3. 0

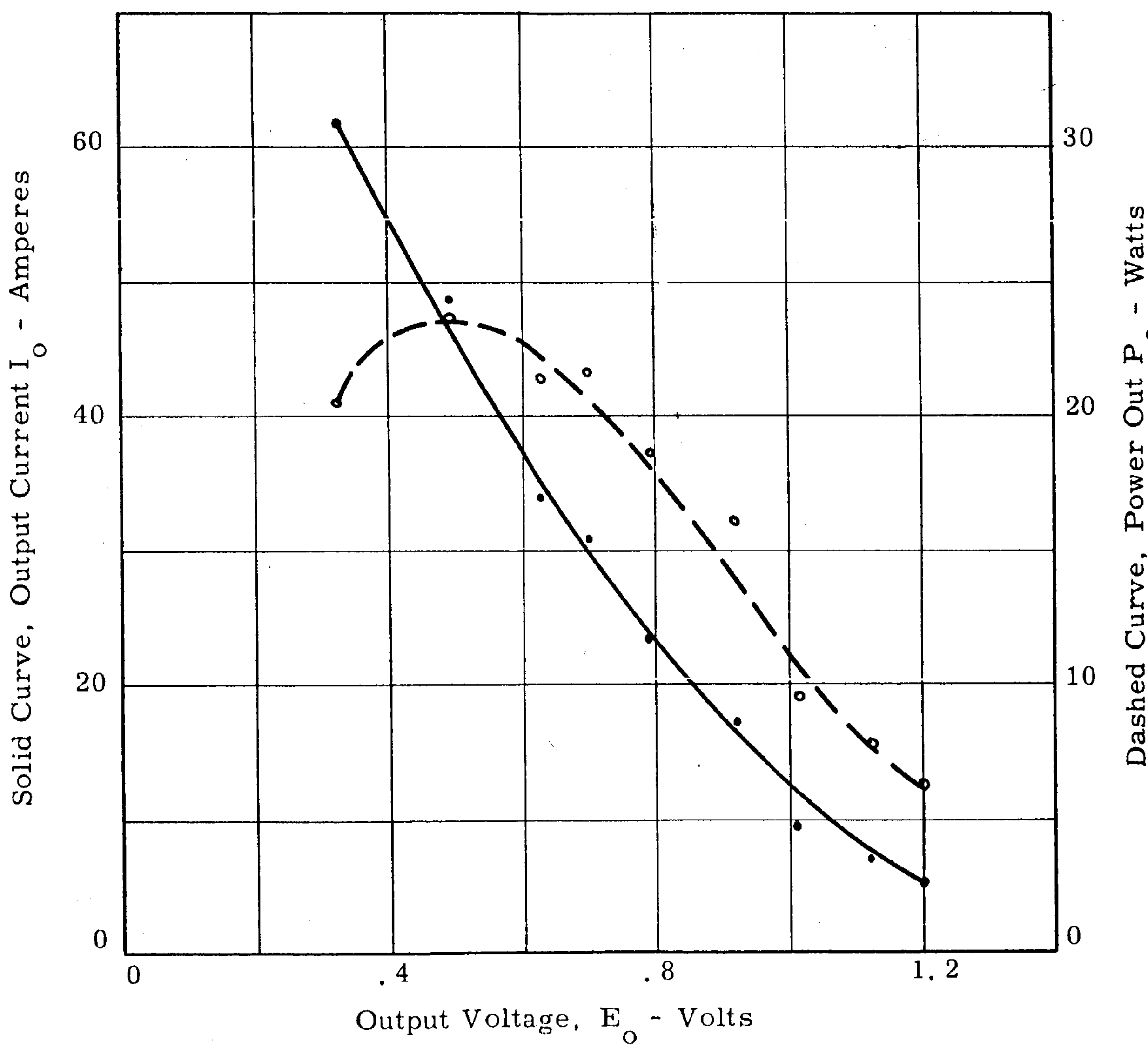


VOLT-AMPERE CURVE, VOLT-POWER CURVE
THERMIONIC CONVERTER
TYPE A-1270, SERIAL NUMBER 11

Operating Conditions	
$T_{emitter}$	1725°C
$T_{collector}$	750°C
T_{cesium}	385°C

Test Data

E_o - Volts	I_o - Amps	P_o - Watts
0.33	62.0	20.4
0.49	48.8	23.9
0.63	34.0	21.4
0.70	31.0	21.7
0.79	23.5	18.6
0.92	17.5	16.1
1.01	9.5	9.6
1.12	7.0	7.8
1.20	5.2	6.3

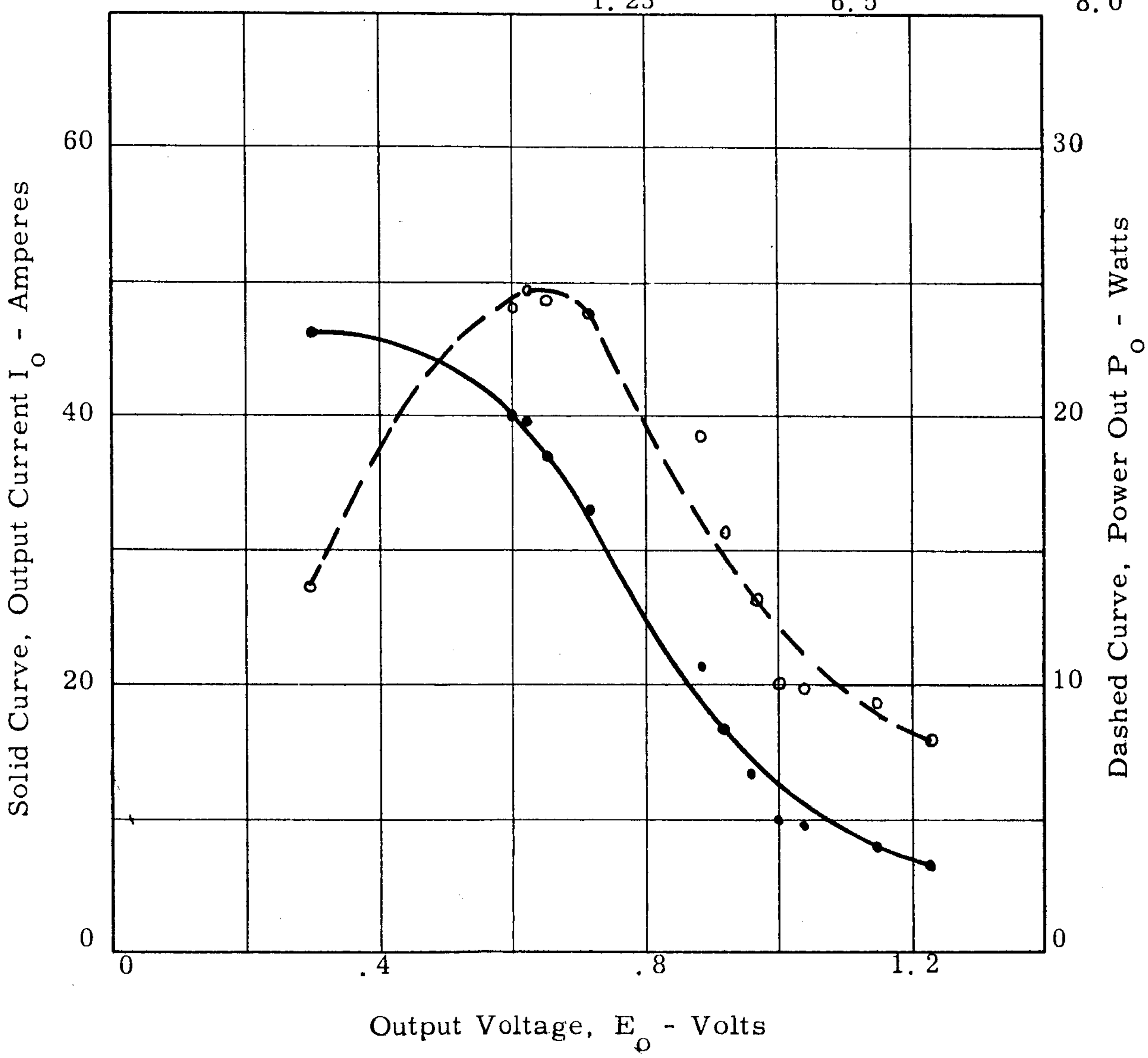


VOLT-AMPERE CURVE, VOLT-POWER CURVE
THERMIONIC CONVERTER
TYPE A-1270, SERIAL NUMBER 12

Operating Conditions	
$T_{emitter}$	1720°C
$T_{collector}$	725°C
T_{cesium}	385°C

Test Data

E_o - Volts	I_o - Amps	P_o - Watts
0.30	46.0	13.8
0.60	40.0	24.0
0.63	39.6	24.6
0.66	37.0	24.3
0.72	33.0	23.7
0.89	21.5	19.2
0.92	17.0	15.6
0.96	13.5	13.0
1.00	10.0	10.0
1.04	9.5	9.8
1.15	8.0	9.4
1.23	6.5	8.0

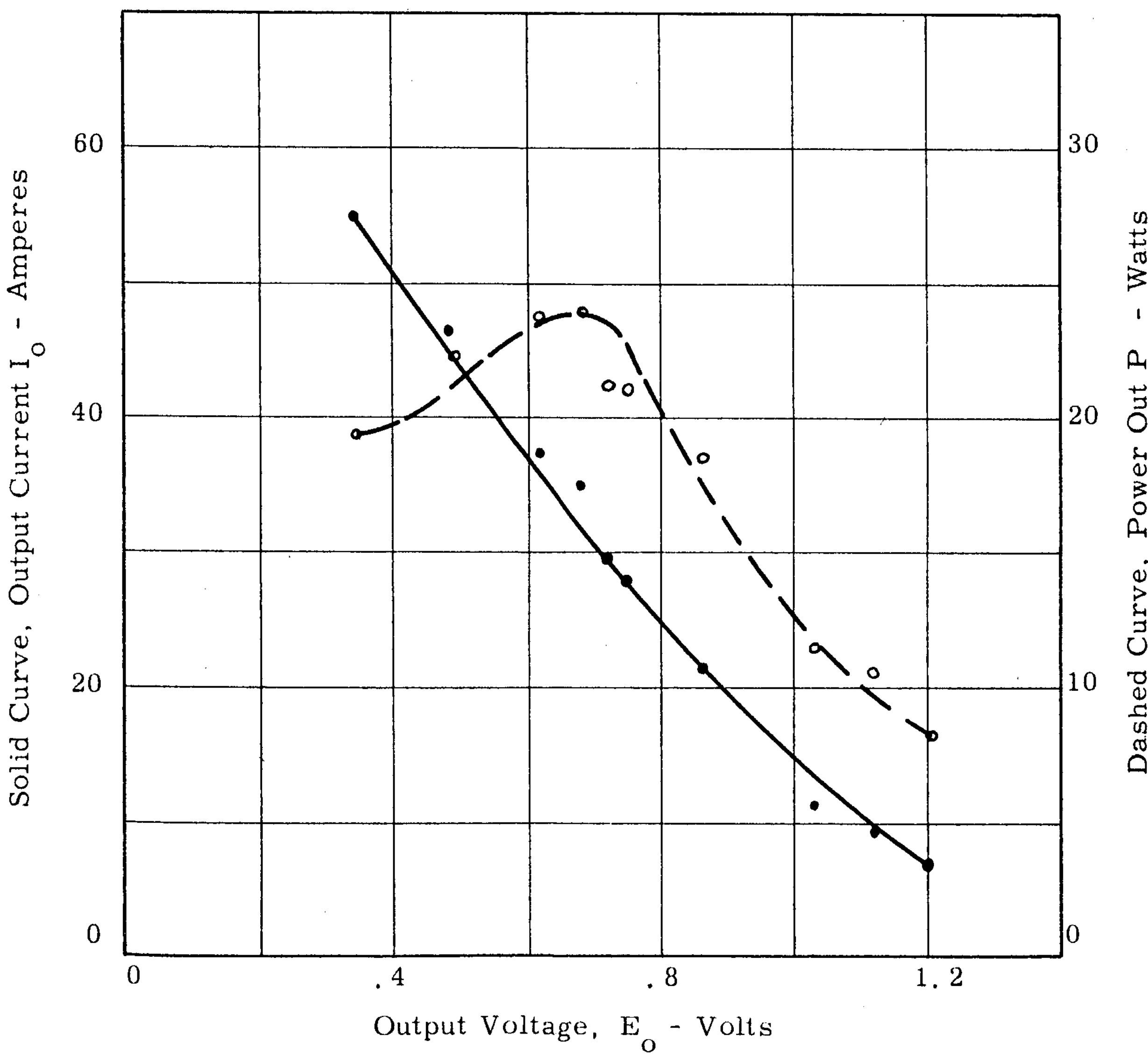


VOLT-AMPERE CURVE, VOLT-POWER CURVE
THERMIONIC CONVERTER
TYPE A-1270, SERIAL NUMBER 13

Operating Conditions	
$T_{emitter}$	1720°C
$T_{collector}$	750°C
T_{cesium}	385°C

Test Data

E_o - Volts	I_o - Amps	P_o - Watts
0.35	55.0	19.3
0.48	46.5	22.3
0.62	37.5	23.6
0.68	35.0	23.8
0.72	29.5	21.2
0.75	28.0	21.0
0.86	21.5	18.5
1.03	11.5	11.9
1.12	9.5	10.6
1.20	7.0	8.4

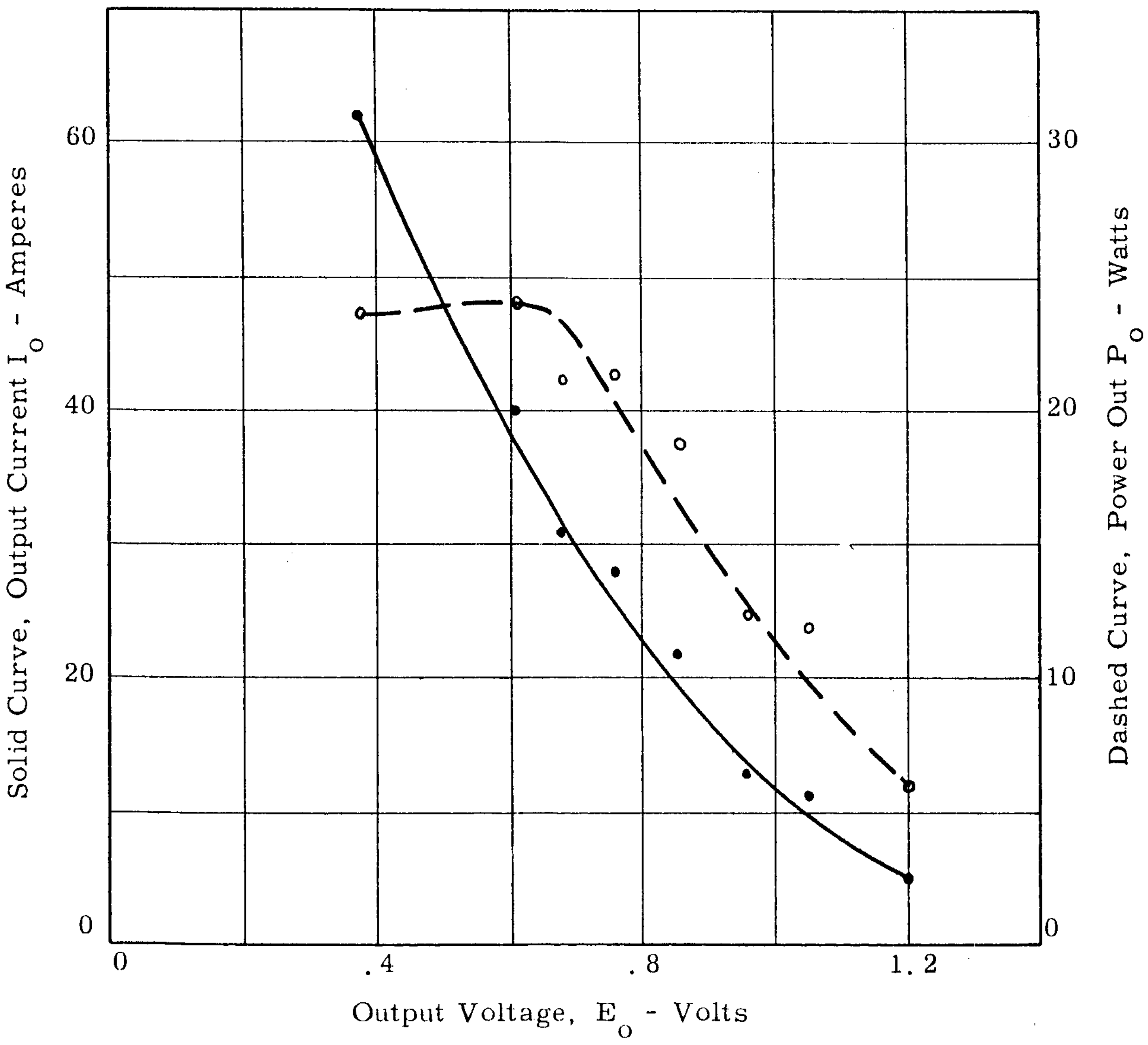


VOLT-AMPERE CURVE, VOLT-POWER CURVE
THERMIONIC CONVERTER
TYPE A-1270, SERIAL NUMBER 14

Operating Conditions	
$T_{emitter}$	1720°C
$T_{collector}$	750°C
T_{cesium}	390°C

Test Data

E_o - Volts	I_o - Amps	P_o - Watts
0.38	62.0	23.5
0.61	40.0	24.4
0.68	31.0	21.1
0.76	28.0	18.7
0.85	22.0	18.7
0.95	13.0	12.3
1.05	11.3	11.9
1.20	5.0	6.0

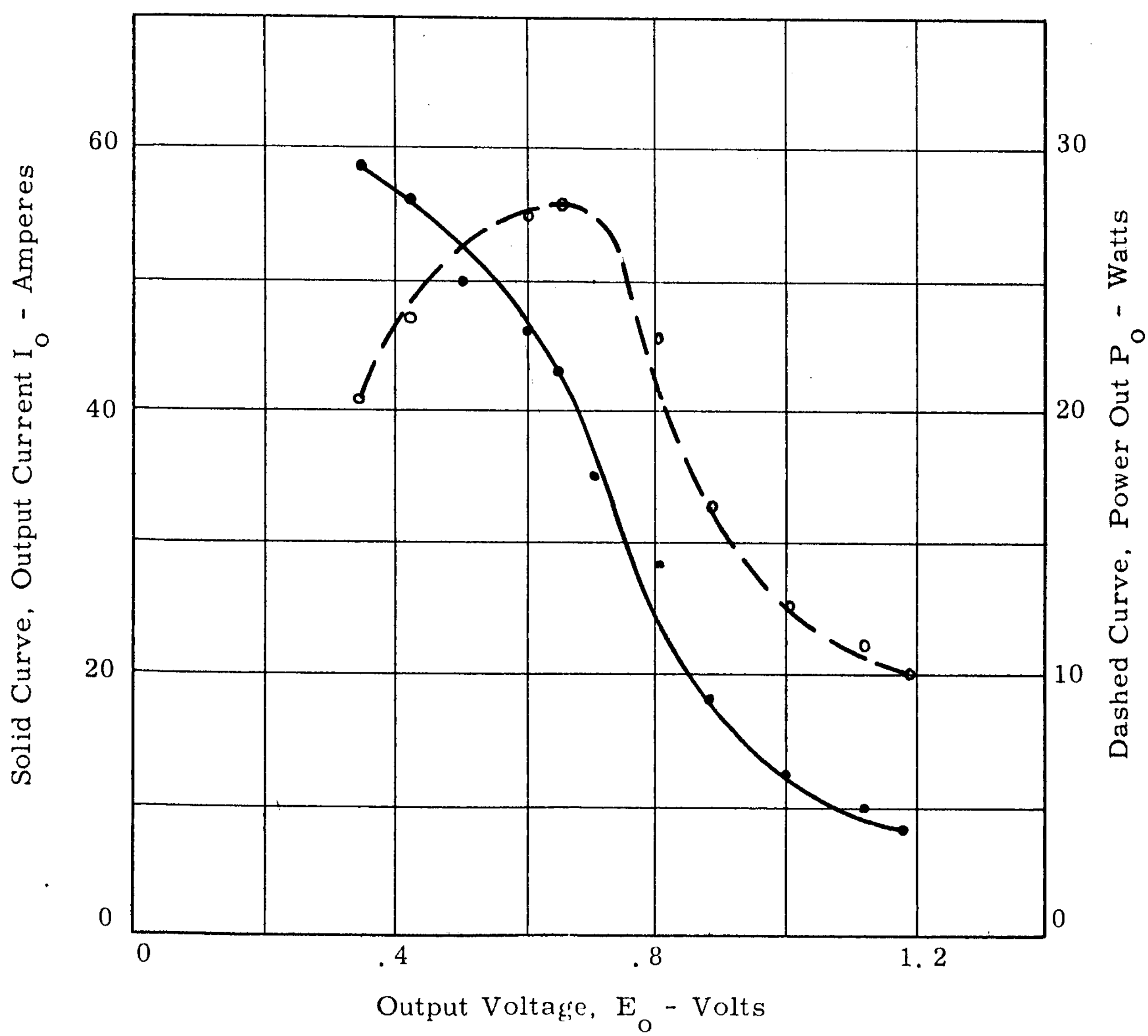


VOLT-AMPERE CURVE, VOLT-POWER CURVE
THERMIONIC CONVERTER
TYPE A-1270, SERIAL NUMBER 15

Operating Conditions	
$T_{emitter}$	1700°C
$T_{collector}$	775°C
T_{cesium}	390°C

Test Data

E_o - Volts	I_o - Amps	P_o - Watts
0.35	58.5	20.4
0.42	56.0	23.5
0.51	50.0	25.0
0.60	46.0	27.5
0.65	43.0	28.0
0.72	35.0	25.0
0.81	28.5	22.8
0.88	18.5	16.3
1.00	12.5	12.5
1.12	10.0	11.2
1.18	8.5	10.0



VOLT-AMPERE CURVE, VOLT-POWER CURVE
THERMIONIC CONVERTER
TYPE A-1270, SERIAL NUMBER 16

APPENDIX A

HEAT LOSS DETERMINATIONS

RCA DEVELOPMENTAL CONVERTER TYPE A-1270

Prepared For:

JET PROPULSION LABORATORIES
California Institute of Technology
Pasadena, California

CONTRACT NAS-7-100
P. O. NO. 950229

Final Technical Report
Contract NAS-7-100
18 December 1962

APPENDIX A
HEAT LOSS DETERMINATIONS

A Emitter Lead Loss

$T_k = 1700°\ C$

$T_{Heat\ Dam} = 600°\ C$

$I = 33.2$ Amps

P_{T_a} at $1100°\ C = 59 \times 10^{-6}$ ohm-cm

K_{T_a} at $1100°\ C = 0.65$ watts/cm °C

$N_o = 15$ o/o $\quad \Delta T = 1100°\ C$

$$\frac{A}{L} = I \left(\frac{\rho}{K \Delta T\ N_o} \quad (1 - \frac{N_o}{2}) \right)^{1/2}$$

$$\frac{A}{L} = 33.2 \quad \left(\frac{59 \times 10^{-6}}{(0.65)\ (1100)\ (0.15)} \quad (1 - \frac{0.15}{2}) \right)^{1/2}$$

$$\frac{A}{L} = 33.2 \quad \left(0.508 \times 10^{-6} \right)^{1/2}$$

$$\frac{A}{L} = \underline{\underline{0.0236}} \quad \frac{cm^2}{cm}$$

Assume $L = 2.5$ cm,

then $A = 2.5 \times 0.0236 = 0.059\ cm^2$

If $A = \pi DS$ where $D = 0.665\ in \times 2.54\ \frac{cm}{in}$

S = thickness of heat dam wall,

then

$$S = \frac{A}{\pi D} = \frac{0.059\ cm^2}{(3.14)\ (0.665)\ (2.54)} = 0.0111\ cm$$

$$S = \underline{\underline{0.00438\ \text{inches}}}$$

A heat dam of 0.0028 inch thickness is considered undesirably thin by RCA for reasons of mechanical strength. Therefore, to prevent excessive weakness a 0.005 inch wall thickness was used.

1. Heat Flow Down Emitter Lead

Emitter Diameter = 0.661 inch x 2.54 cm/in

Emitter Wall (S) = 0.005 inch x 2.54 cm/in

Emitter Length (L) = 2.54 cm

Thermal Conductivity at T_a at 1100° C = 0.65 watts/cm^2

$A = 0.067\ cm^2$

$\Delta T = 1700 - 600 = 1100°\ C$

$$W = \frac{KA\Delta T}{L} = \frac{(0.65)\ (0.067)\ (1100)}{2.5} = \underline{\underline{19.3 \text{ watts}}}$$

Since the modification of the emitter lead was in the low temperature area, relatively small changes in the losses from the emitter lead were encountered. Temperature measurements taken at the ceramic seal area for converters of the modified and unmodified type show no change. Therefore, the change in heat flow is considered to be negligible and emitter heat loss after modification was determined to be the same as the initial heat loss.

B Collector Heat Losses

The following calculated heat energy must be considered transferred to the collector.

1. Electron Heating

$$P_e = I\ (\phi_c + \frac{2KT}{2}) \quad \text{where } \frac{2K}{e} = 1.723 \times 10^{-4} \text{ watts/amp}$$

$$P_e = 13.3\ \frac{\text{amps}}{\text{cm}^2}\ (1.86\ V + 1.723 \times 10^{-4}\ \frac{\text{watts}}{\text{amp}\ °K} \times 2000°\ K)$$

$$P_e = 24.7 \frac{\text{watts}}{\text{cm}^2} + 4.6 \frac{\text{watts}}{\text{cm}^2} = 29.3 \text{ watts/cm}^2$$

$$P_e = 29.3 \text{ watts/cm}^2 \times 2.07 \text{ cm}^2 = \underline{\underline{60.5 \text{ watts total}}}$$

2. Radiation Loss

a. Radiation Loss (Emitter Force)

$$P_R = \sigma \epsilon \text{ eff } A (T_2^4 - T_1^4)$$

$$P_R = 5.67 \times 10^{-12} \times 0.12 \times 2.07 (2000^4 - 900^4)$$

$$P_R = 21.6 \text{ watts total}$$

$\sigma = 5.67 \times 10^{-12}$ watts/cm^2 °K
$A = 2.07$ cm^2
$T_c = 2000°$ K
$T_A = 900°$ K
$\epsilon\text{eff} = \left(\frac{1}{c} + \frac{1}{A} - 1\right)^{-1}$
$\epsilon\text{eff} = 0.12$

b. Radiation Loss (Emitter Wall - 1 cm lg from face)

$$P_R = 5.67 \times 10^{-12} \times 5.3 (1600^4 - 900^4)$$

$$P_R = 21 \text{ watts total}$$

$\sigma = 5.67 \times 10^{-12}$ watts/cm^2 °K
$A = 0.66/\text{in} \times 17 \times 2.54 \frac{\text{cm}}{\text{in}} \times 1$ cm
$A = 5.3$ cm^2
$T_c = 1600°$ K
$T_A = 900°$ K
$\epsilon\text{eff} = 0.12$

3. Ionization Loss

Ion Power = arc drop x current density
assume arc drop = 0.5 volt
Ion Power = 0.5 volt x 13.3 amp/cm^2 = 6.6 watts/cm^2
or 13.6 watts total

4. Cesium Cooling Losses

a. Gas Transfer

As cooling occurs at 7 watts/cm^2

$$7 \text{ watts} \times 2.07 = \underline{\underline{14.5 \text{ watts}}}$$

Summing up:

1	Electron Heating	60.5 watts
2a	Radiation Loss	21.6 watts
2b	Radiation Loss	21.0 watts
3	Ionization Loss	13.6 watts
4a	Gas Transfer	14.5 watts
	Total	130.2 watts

C. Radiator Change and Reduction of Collector Copper

1. Modified Collector and Radiator Design

What is temperature drop to collector end assuming $T_{collector}$ of 700° Centigrade?

Heat to Anode = 150 watts (130 w plus 20 w safety factor)
Ther. Cond. Mo = 0.29 (4.19) watts/cm^2
Ther. Cond. Cw = 0.93 (4.19) watts/cm^2

$$W = \frac{KA\Delta T}{L}$$

$$\Delta T\,Mo = \frac{W\,L_{Mo}}{K_{Mo}\,A_{Mo}}$$

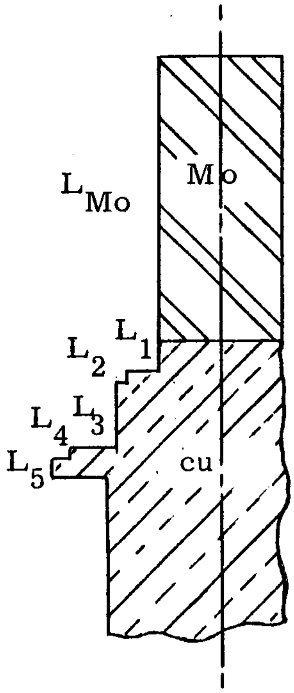
$$\Delta Tcu_1 = \frac{W\,L_1}{Kcw\,A_1}$$

$$\Delta Tcu_2 = \frac{W\,L_2}{Kcw\,A_2}$$

$$\Delta Tcu_3 = \frac{W\,L_3}{Kcw\,A_3}$$

$$\Delta Tcu_4 = \frac{W\,L_4}{Kcw\,A_4}$$

$$\Delta Tcu_5 = \frac{W\,L_5}{Kcw\,A_5}$$



See Drawing 344-3213

$$\Delta T_{Mo} = \frac{(150)\ (1.5)\ (2.54)}{(0.29)\ (4.19)\ (3.14)\ (0.322)^2\ (2.54)^2} = 220° \text{ C}$$

$$\Delta Tcu_1 = \frac{(150)\ (0.20)\ (2.54)}{(0.934)\ (4.19)\ (3.14)\ (0.322)^2\ (2.54)^2} = 9.25° \text{ C}$$

$$\Delta Tcu_2 = \frac{(150)\ (0.050)\ (2.54)}{(0.934)\ (4.19)\ (3.14)\ (0.50)^2\ (2.54)^2} = 0.96° \text{ C}$$

$$\Delta Tcu_3 = \frac{(150)\ (0.35)\ (2.54)}{(0.934)\ (4.19)\ (3.14)\ (0.65)^2\ (2.54)^2} = 3.99° \text{ C}$$

$$\Delta Tcu_4 = \frac{(150)\ (0.05)\ (2.54)}{(0.934)\ (4.19)\ (3.14)\ (0.75)^2\ (2.54)^2} = 0.425° \text{ C}$$

$$\Delta Tcu_5 = \frac{(150)\ (0.90)\ (2.54)}{(0.934)\ (4.19)\ (3.14)\ (0.60)^2\ (2.54)^2} = \underline{12° \text{ C}}$$

Total = 247° C

Therefore, temperature at point of anode radiator attachment = 700° C - 247° C = <u>453° C</u>

Assume no more than 10° drop down anode radiator tolerable.

Therefore, we radiate 150 watts at 450° Centigrade.

$$P_R = \sigma A \in_{eff} (T_2^4 - T_1^4)$$

$\in$ radiator = 0.9

$\in$ glass = 0.7

$\in$ eff $= \left(\frac{1}{0.9} + \frac{1}{0.7} - 1\right)^{-1} = 0.655$

T_1 = 50° C = 323° K

T_2 = 450° C = 723° K

σ = 5.67×10^{-12} w/cm^2 °K

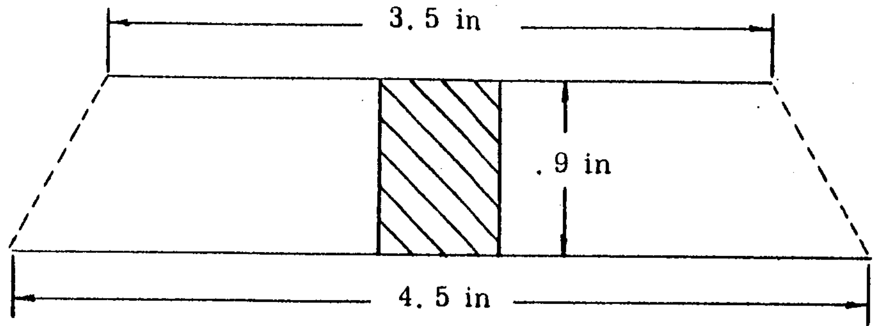
P_R = 150 watts

$$A = \frac{P}{\sigma \in_{eff} (T_2^4 - T_1^4)}$$

$$A = \frac{150}{5.67 \times 10^{-12} (0.655) \quad 723^4 - 323^4}$$

$A = \underline{\underline{155 \text{ cm}^2}}$ of radiator area needed to radiate 150 watts at 450° C.

2. Radiator Geometry



Radiator Average Dia. $= \frac{4.5'' + 3.5''}{2} = 4''$ or 16.16 cm

Radiator Length = 1 inch or 2.54 cm

Average Projected Area $(A_1) = \pi dL = (3.14)(10.16)(2.54) = \underline{\underline{81 \text{ cm}^2}}$

Area of Large Fin $(A_2) = \pi R^2 = (3.14)(5.72)^2 = 102.5 \text{ cm}^2$

$$R = \frac{4.5 \times 2.54}{2}$$

$$R = 5.72 \text{ cm}$$

$A_2 = 102.5$ - Area of Cs. Res. $(5.1) = \underline{\underline{97.4 \text{ cm}^2}}$

Radiator can radiate from projected area (A_1) and large fin Area (A_2), as follows:

$$P_1 = \sigma \epsilon_{eff} A_1 (T_2^4 - T_1^4) = 5.67 \times 10^{-12} (0.655)(81)(723^4 - 323^4)$$

$$P_1 = 80 \text{ watts}$$

$$P_2 = \sigma \epsilon_{eff} A_2 (T_2^4 - T_1^4) = 5.67 \times 10^{-12} (0.655)(97.4)(723^4 - 323^4)$$

$$P_2 = 91 \text{ watts}$$

Therefore, with collector temperature of 700° C a radiator of geometry described can radiate a total of 80 + 91 = 171 watts. Since the actual calculated power loss to the collector is 130 watts, such a radiator should be sufficient.

Considering the ratio of slot depth to fin spacing, it is seen that seven fins provide an 8:1 ratio which should give an emissivity of 0.9.

Then for the A_1 radiator area, approximately 10 watts/fin must be radiated. In other words, 10 watts/fin x 7 fins = 70 watts + 90 watts radiated by the A_2 radiator area should be sufficient. Assuming copper fins, no more than 20° C drop across fin.

$$A = \frac{WL}{K\Delta T} = \frac{10(3.56\ \text{cm})}{(0.943)(4.19)(20)}$$

$$A = 0.45\ \text{cm}^2$$

$W = 10$ w/fin

Ave. $L = 1.4\ \text{in} \times 2.54\ \frac{\text{cm}}{\text{in}}$

Ave. $L = 3.56$ cm

K_{cu} at 20°C = 0.943 x 4.19 w/cm °C

$\Delta T = 20°$ C

then:

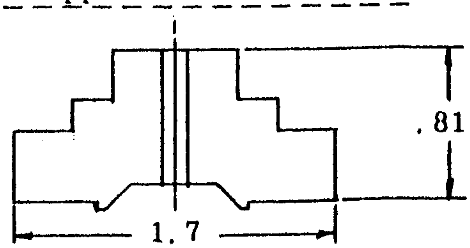
$A = \pi ds$ where d = ave. fin length

$$d = \frac{4.5 + 3.5}{4} = 2 \text{ inches or } 5.08 \text{ cm}$$

$$S = \frac{A}{\pi d} = \frac{0.45}{3.14 \times 5.08} = 0.028 \text{ inch}$$

Therefore, if 0.030 copper is used for fins no more than 20° C drop will occur from the center of the fin to the outer diameter of the fin.

3. New Copper Section of Anode



See Drawing 344-2101

ΔT_1 down copper to fin attachment area?

$$W = \frac{KA\Delta T}{L} \qquad \Delta T = \frac{WL}{KA}$$

Assume Ave. A
W = 150 watts
L = 0.7 in

$$\Delta T_1 = \frac{(150)\ (0.7)\ (2.54)}{(0.934)\ (4.19)\ (0.625)^2\ (2.54)^2}$$

$$\Delta T_1 = 28°\ C$$

ΔT_2 = drop down Mo section of anode = 225° C

Temperature at radiator = 800° C - (225° C + 28° C)

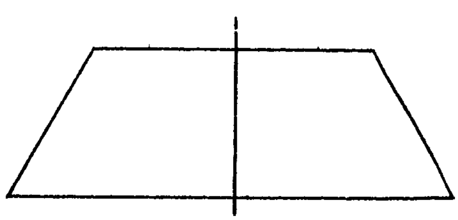
Temperature at radiator = 550° C or 825° K

$$P_R = \sigma \in eff\ A\ (T_1^4 - T_2^4)$$

$$A = \frac{P_R}{\sigma \in eff\ (T_1^4 - T_2^4)} = \frac{150}{5.67 \times 10^{-12}\ (0.655)\ (825^4 - 324^4)}$$

A = 95.5 cm^2 or $\approx$ 15 in^2 of radiator area.

If cone shaped design used -



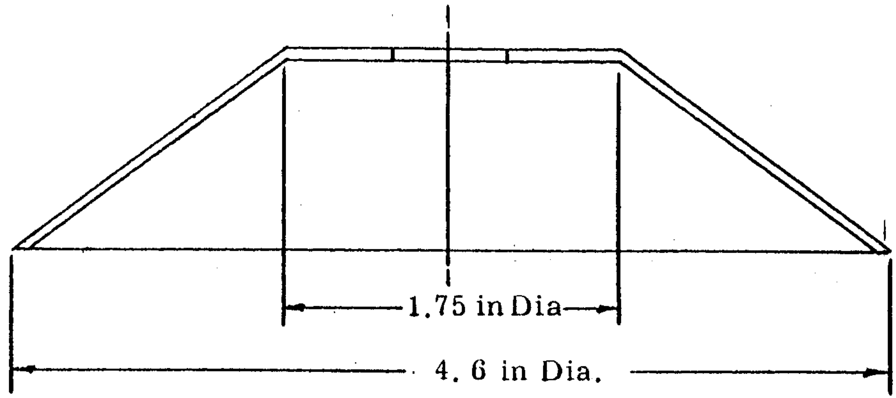
See Drawing 344-2100

Area Cone = ave. dia. x π x lg. of one side

$15 = D\ ave.\ x \pi x\ 1.5\ in$ assume 1.5

$$d\ ave. = \frac{15''\ sq.}{(3.14)\ (1.5\ in)} = \underline{3.18''}\ ave.\ dia.$$

Therefore, radiator of a geometry as follows, will radiate 150 watts at a collector temperature of 800° C.



4. Cesium Reservoir Lead

Assume - stainless steel tubing 0. 010" wall x 1/4" O. D. for lead.

(a) What power can the reservoir proper radiate assuming a ΔT = 100° Centigrade?

$$P_R = \sigma \sum \text{eff } A \, (T_2^4 - T_1^4)$$

$$P_R = 5.67 \times 10^{-12} \, (0.114) \, (5.1) \quad (623)^4 - (293)^4$$

$$P_R = 0.254 \text{ watts}$$

$$\sigma = 5.67 \times 10^{-12} \text{ w/cm}^2 \, {}^\circ\text{K}$$

$$\epsilon \text{ eff} = \left(\frac{1}{.12} + \frac{1}{.7} - 1\right)^{-1} = .114$$

$$A = 5.1 \text{ cm}^2$$

$$T_2 = 623^\circ \text{ K}$$

$$T_1 = 293^\circ \text{ K}$$

Assuming lead length = 1. 5 inches, what ΔT will result if we assume that 0. 254 watts is conducted down lead?

$$\Delta T = \frac{WL}{KA} = \frac{0.254 \times 1.5 \times 2.54}{0.058 \times 0.05 \text{ cm}^2}$$

$$K_{ss} = 0.058 \text{ w/cm } {}^\circ\text{C at } 400^\circ \text{ C}$$

$$A = \pi DS = 0.05 \text{ cm}^2$$

$$\Delta T = 334^\circ \text{ C}$$

APPENDIX B

BILL OF MATERIALS

RCA DEVELOPMENTAL CONVERTER A-1270

Prepared For:

JET PROPULSION LABORATORIES
California Institute of Technology
Pasadena, California

CONTRACT NAS-7-100
P.O. NO. 950229

Final Technical Report
18 December 1962

APPENDIX B

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Crossection Drawing	344-2233	-	B-3
Emitter Assembly	344-2042	-	B-4
Emitter, Blunt End	344-2150	Tantalum	B-5
Emitter, Rolled Blunt End	344-2149	Tantalum	B-6
Emitter, Blank Blunt End	344-2148	Tantalum	B-7
Emitter	344-2087	Tantalum	B-8
Emitter, Rolled	344-2088	Tantalum	B-9
Emitter, Blank	344-2089	Tantalum	B-10
Emitter Support	344-2030	Molybdenum	B-11
External Emitter Lead	344-2048	Nickel	B-12
Insulator Assembly	344-2103	-	B-13
Strain Isolation Ring, Small	344-2037	Kovar	B-14
Ceramic Insulator	344-2043	Ceramic	B-15
Strain Isolation Ring	344-2038	Kovar	B-16
Generator Support Ring Assembly	344-2049	-	B-17
Generator Support Ring	344-2050	Kovar	B-18
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Solder Washer	344-2054	Copper	B-20
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Ceramic Insulator	344-2051	Ceramic	B-22
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Exhaust Line Tubing	344-2122	Copper	B-28
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Test Mount, Jigs and Fixtures

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Exhaust Tubing	14061	OFHC Cpr.	B-41
Exhaust Joint	14062	OFHC Cpr.	B-42
Cesium Tubing	14063	OFHC Cpr.	B-43
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Cylinder	14080	St. Steel	B-58
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Test Mount, Jigs and Fixtures
(Continued)

Drawing Title	Drawing Number	Material	Page Number
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Punch Barrel	14105	Vasco Supreme	B-76
Weight	14123	St. Steel	B-77
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Weight	14125	St. Steel	B-79
Split Ring	14126	St. Steel	B-80
Base	14127	St. Steel	B-81
Brazing Base	14131	St. Steel	B-82
Brazing Jig	14132	St. Steel	B-83
Rubber Die Solder Washer	14143	Rubber	B-84
Brazing Jig	14144	-	B-85
Emitter Weight	14145	St. Steel	B-86
Generator Support Ring, Weight	14146	St. Steel	B-87
Split Ring	14147	St. Steel	B-88
Base	14148	St. Steel	B-89
Grinding Fixture	14151	St. Steel	B-90

Brazing Materials:

Zirconium

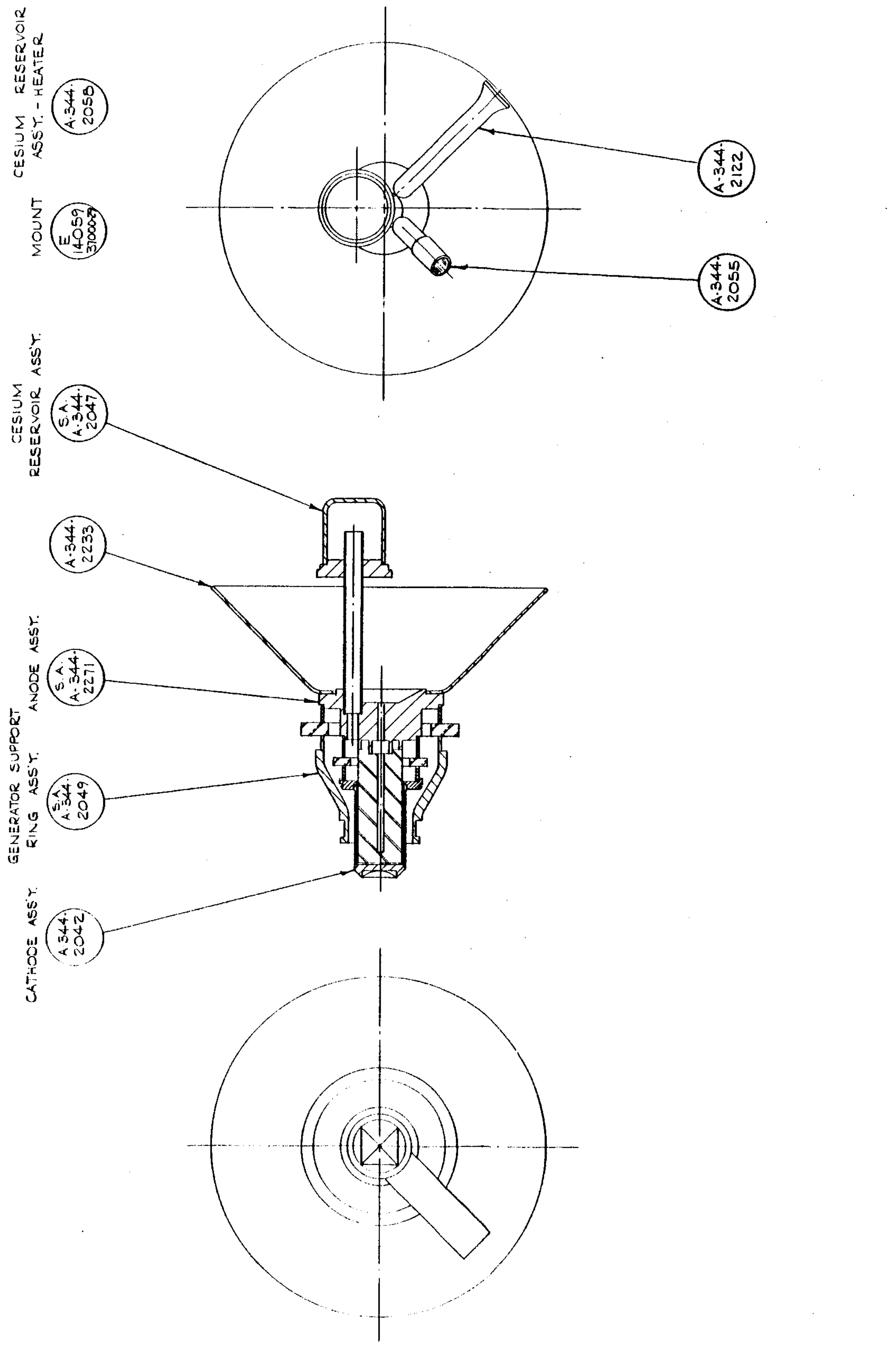
OFHC Copper

Nicrobraze 30 - 19% Cr - 10% Si - 15% C - Bal Ni

Nicoro Braze - 3% Ni - 35% Au - Bal. Cu

BT - Silver - Copper Eutectic - 28% Copper - 72% Silver

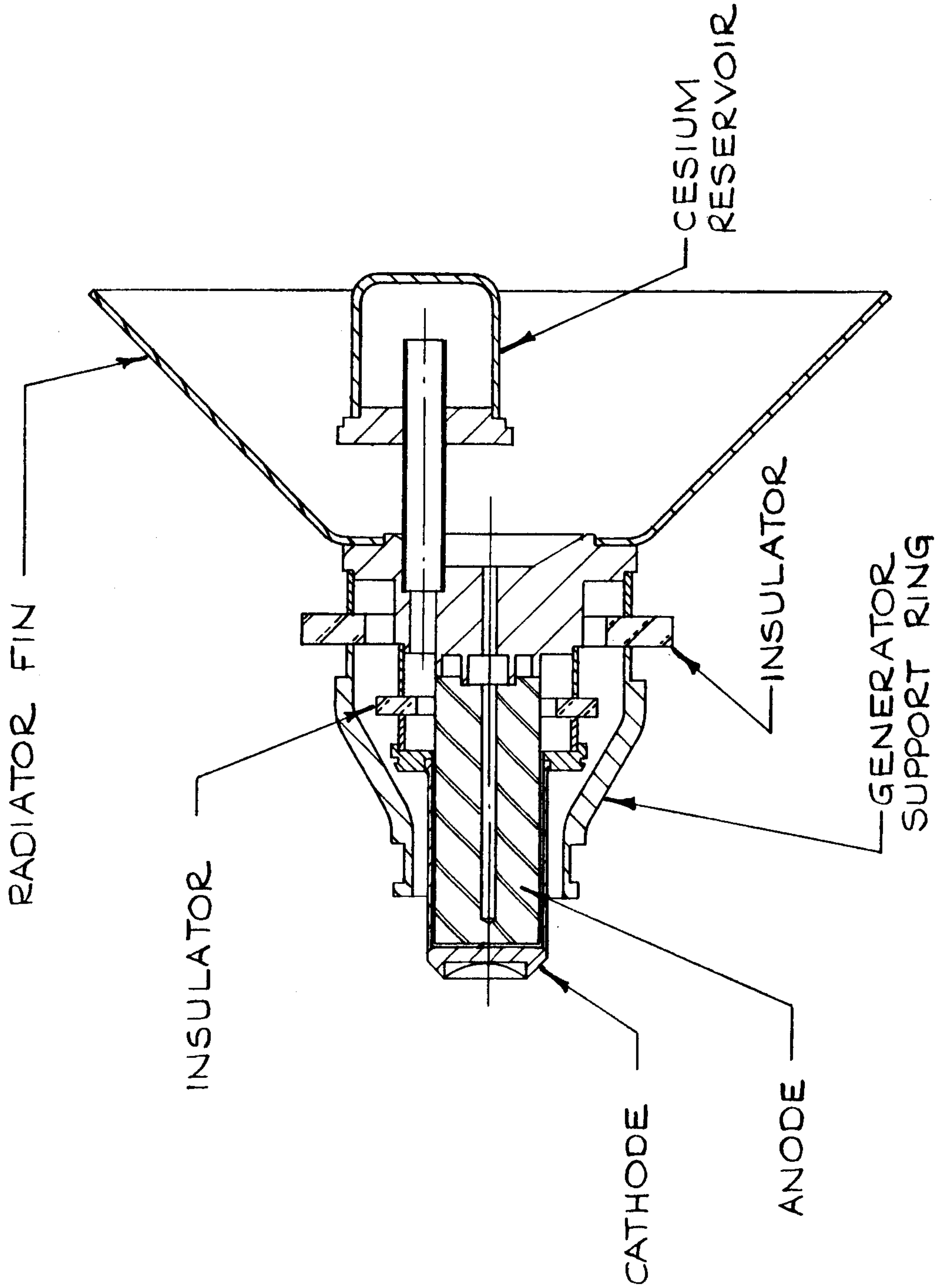
STANDARD TOLERANCE				NOTE: THREADS EXTERNAL, CLASS 2A; INTERNAL, CLASS 2B (AMERICAN STDS) UNLESS OTHERWISE SPECIFIED.
BASIC DIM.		FRAC.	DEC.	
UP TO 6"	±	1/64	.005	SURFACE ROUGHNESS OF 500 MICRO-INCHES OR STOCK FINISH ACCEPTABLE UNLESS OTHERWISE SPECIFIED.
ABOVE 6"	±	1/32	.010	
ABOVE 24"	±	1/16	.015	NOTE: SUPPLY ALL SCREWS, NUTS, BOLTS, RIVETS, WASHERS, DOWELS, TAPER PINS, COTTER PINS & WOODRUFF KEYS WITH PART.
ANGULAR DIM. ± 1/2°				



NOTES:
1. ASSEMBLY MUST BE VACUUM TIGHT.

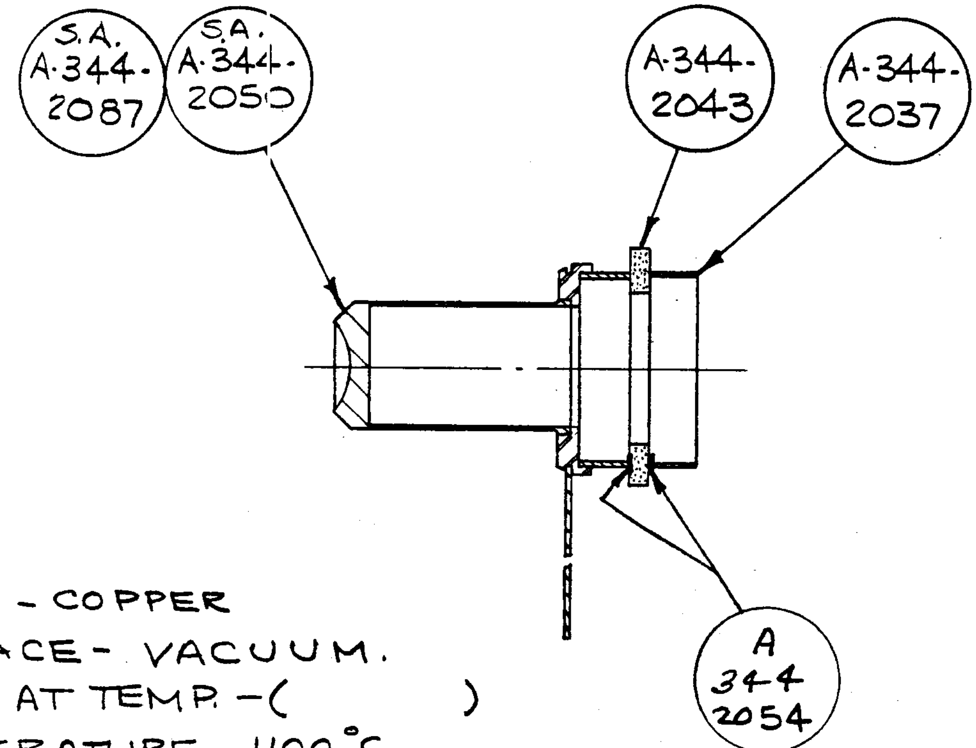
COMPLETE CONVERTER ASSEMBLY

344-3230



CROSSECTION DRAWING

344-2233

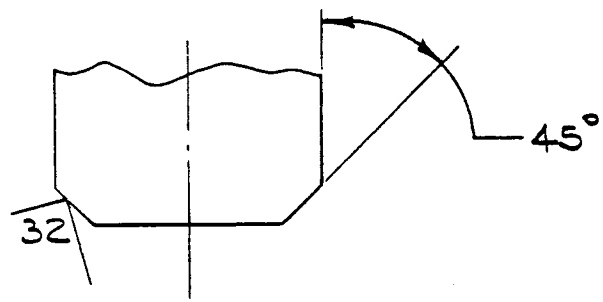


BRAZE - COPPER
FURNACE - VACUUM.
TIME AT TEMP. - (   )
TEMPERATURE 1100 °C.
JIG No 37000-T7-29.
JIG No 37000-T4-29.

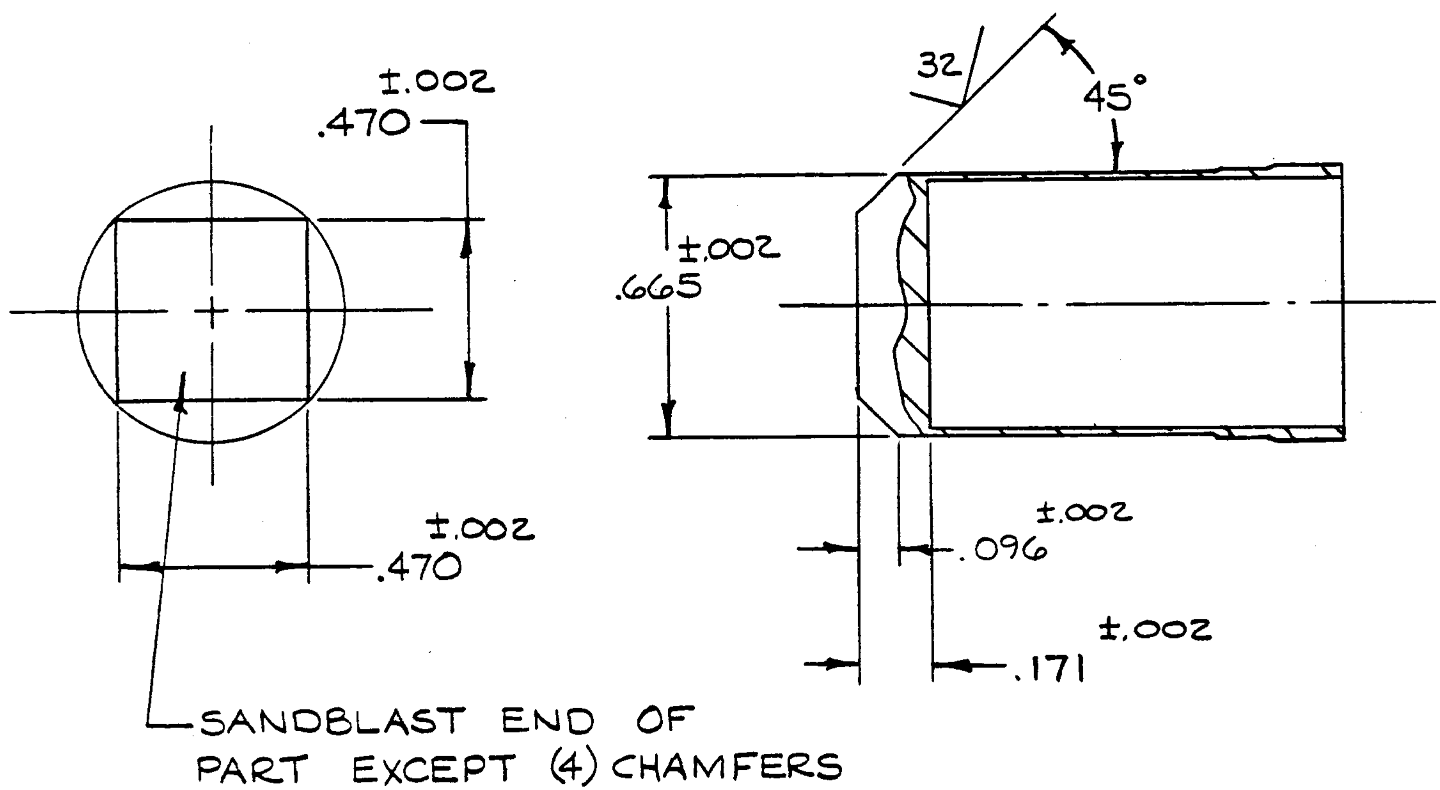
NOTE: BRAZED ASSY. MUST BE VACUUM TIGHT.

EMITTER ASSEMBLY

344-2042

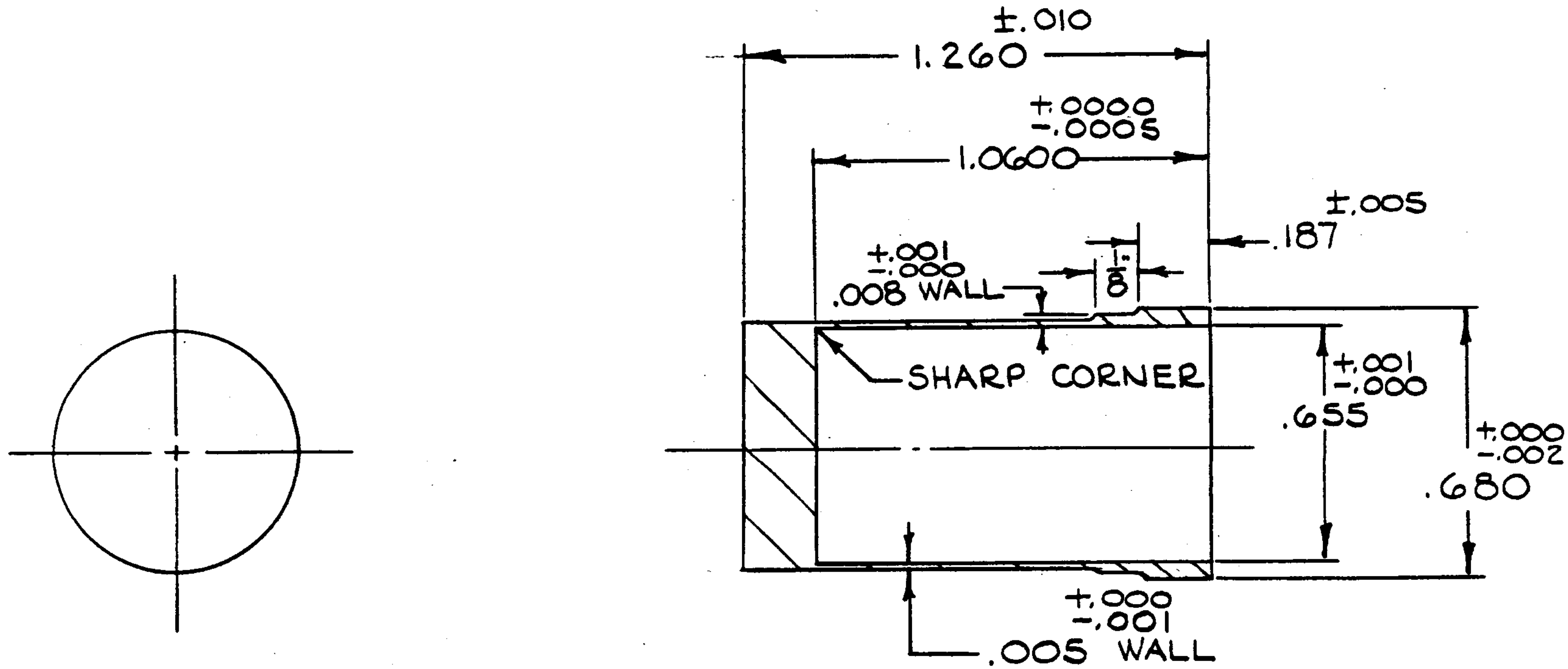


NOTES:
1. WASH W612.
2. FIRE VACUUM 2000°C (1) MIN.
3. STORE IN CLEAN CONTAINER.



EMITTER, BLUNT END

344-2150

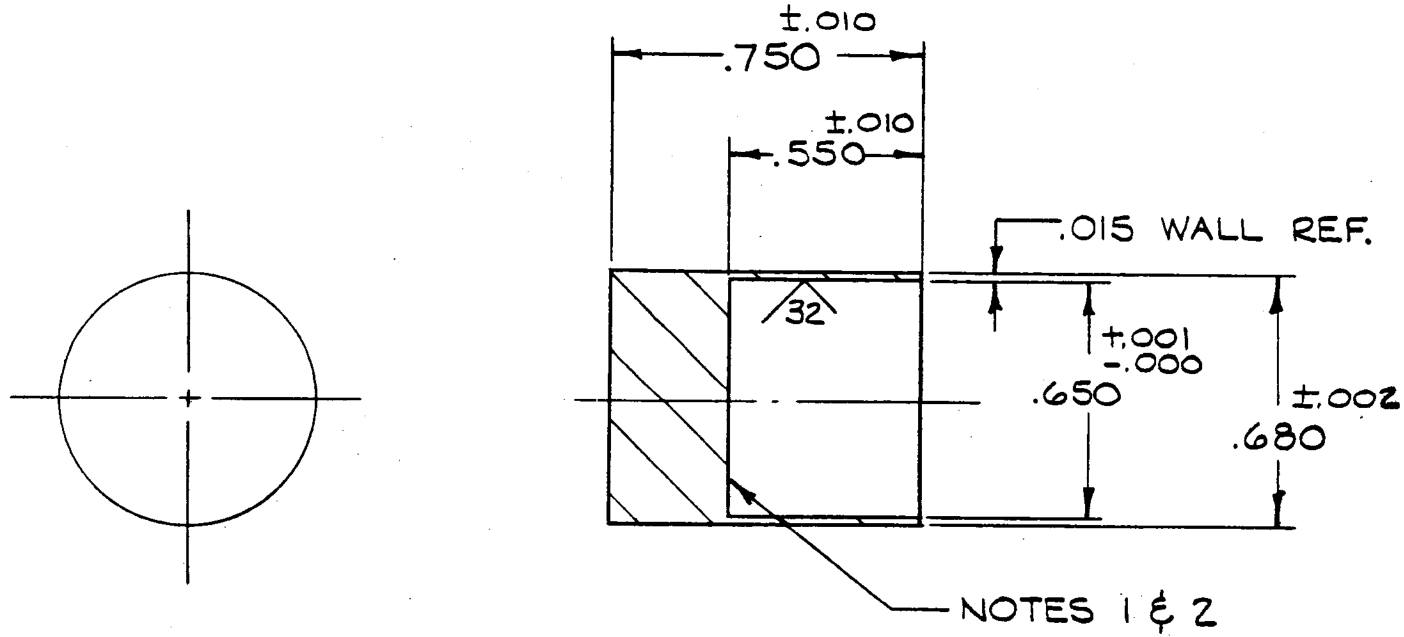


NOTES:

1. PART MUST BE VACUUM TIGHT.

EMITTER, ROLLED BLUNT END

344-2149

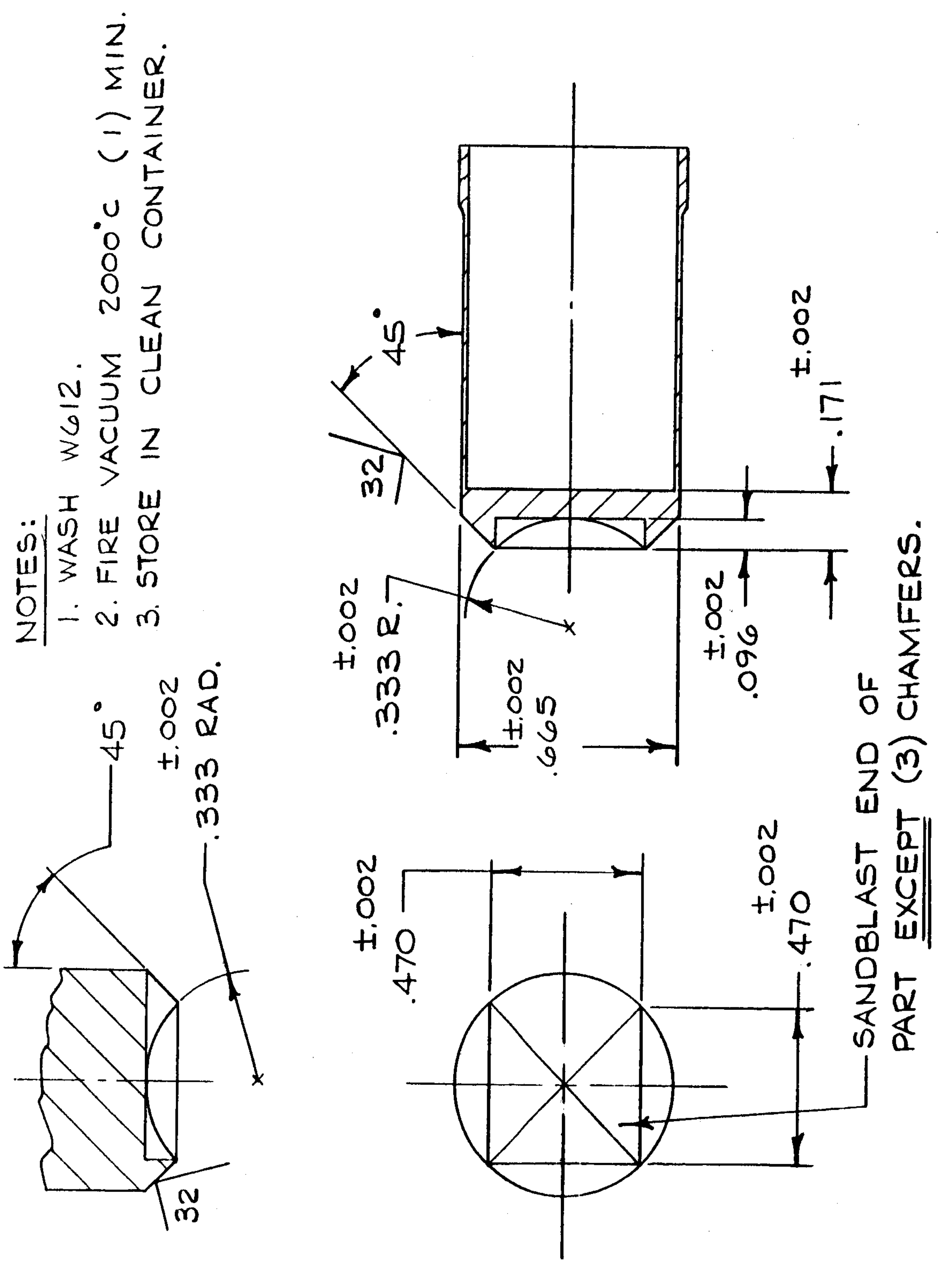


NOTES:

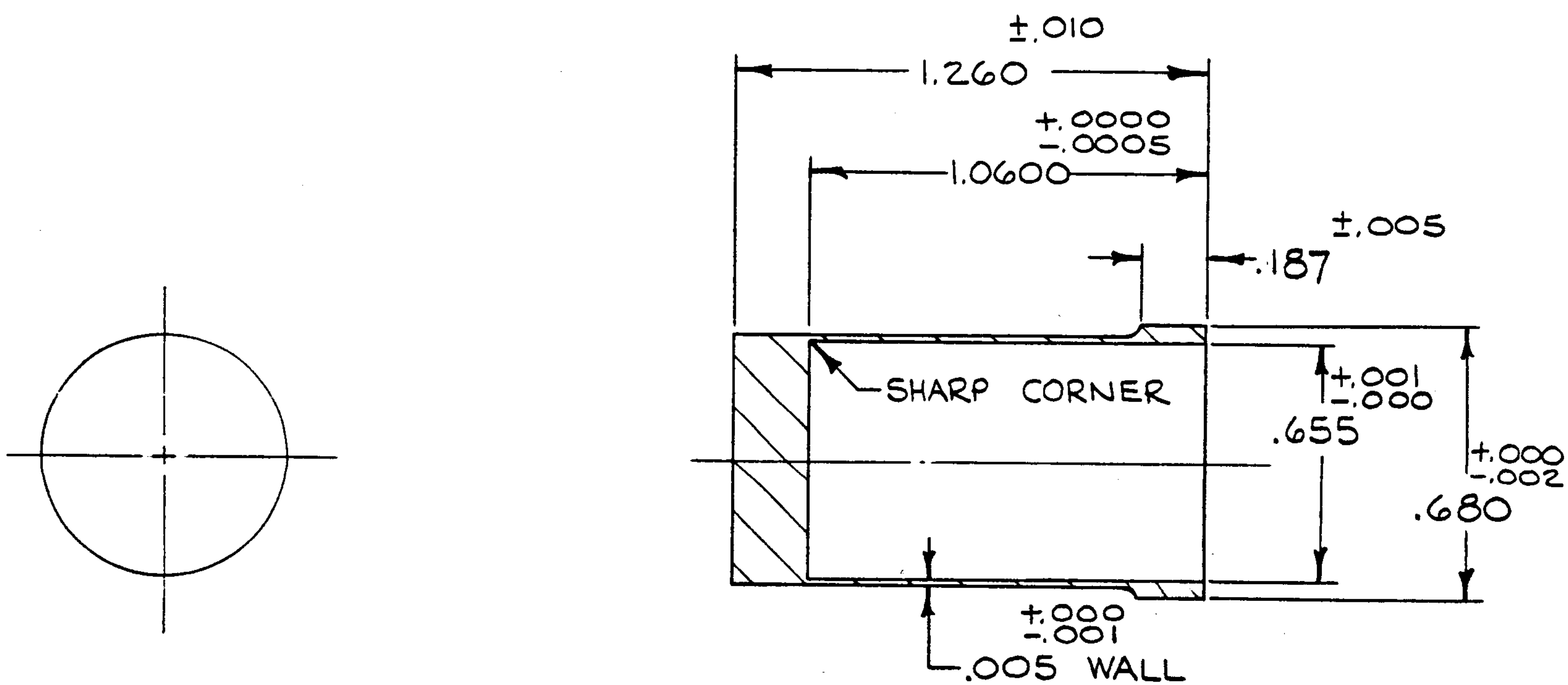
1. THIS SURFACE TO HAVE A 16 ✓.
2. THIS SURFACE TO BE PERPENDICULAR TO I.D. OF PART WITHIN .001.

EMITTER, BLANK BLUNT END

344-2148



EMITTER
344-2087

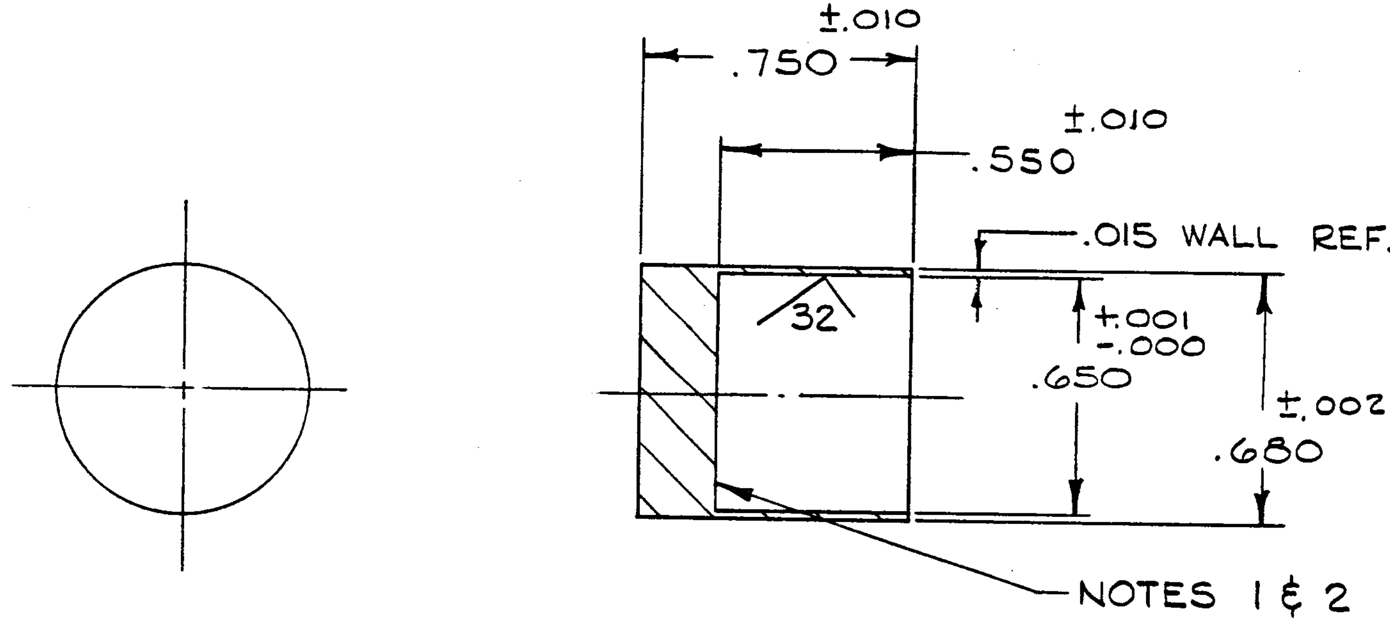


NOTES:

1. PART MUST BE VACUUM TIGHT.

EMITTER, ROLLED

344-2088

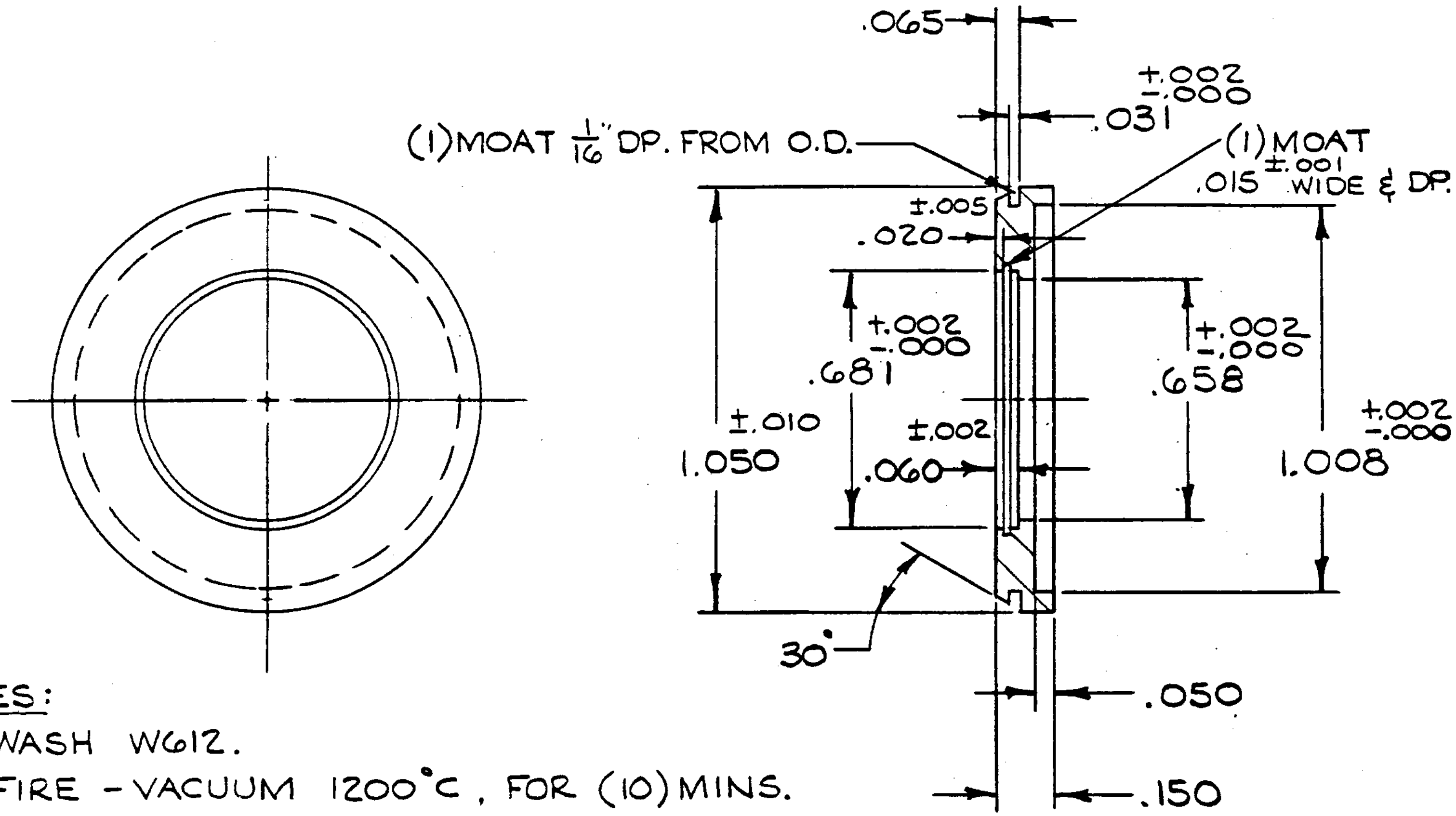


NOTES:

1. THIS SURFACE TO HAVE A 16 √.
2. THIS SURFACE TO BE PERPENDICULAR TO I.D. OF PART WITHIN .001.

EMITTER, BLANK

344-2089

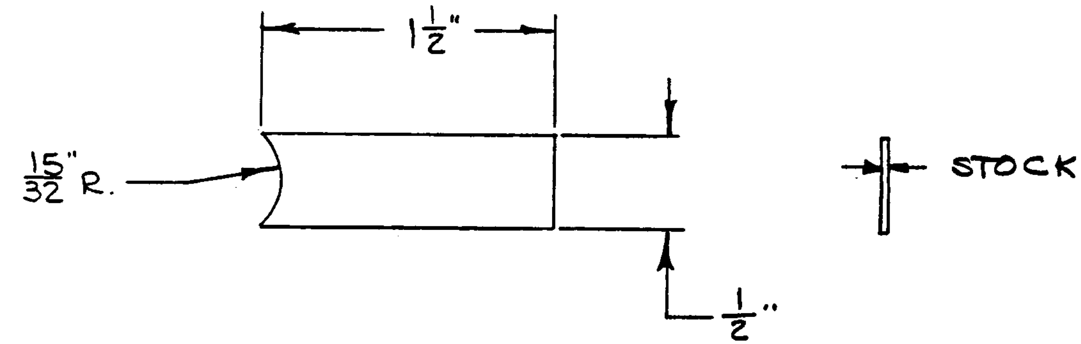


NOTES:

1. WASH W612.
2. FIRE - VACUUM 1200°C, FOR (10) MINS.
3. STORE IN CLEAN CONTAINER.

EMITTER SUPPORT

344-2030

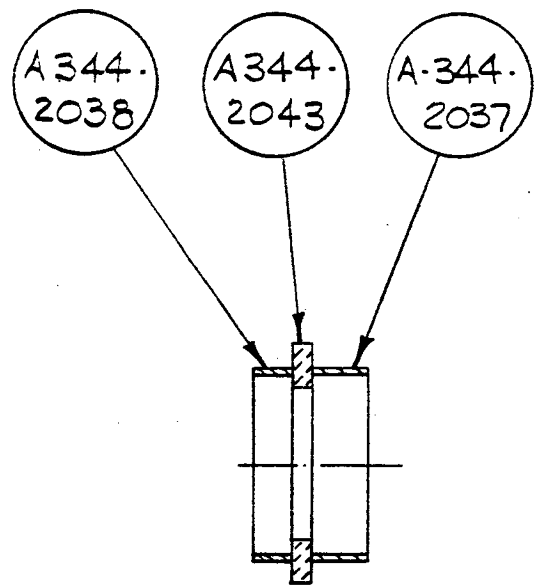


NOTES:

1. WASH W612.
2. STORE IN CLEAN CONTAINER.

EXTERNAL EMITTER LEAD

344-2048

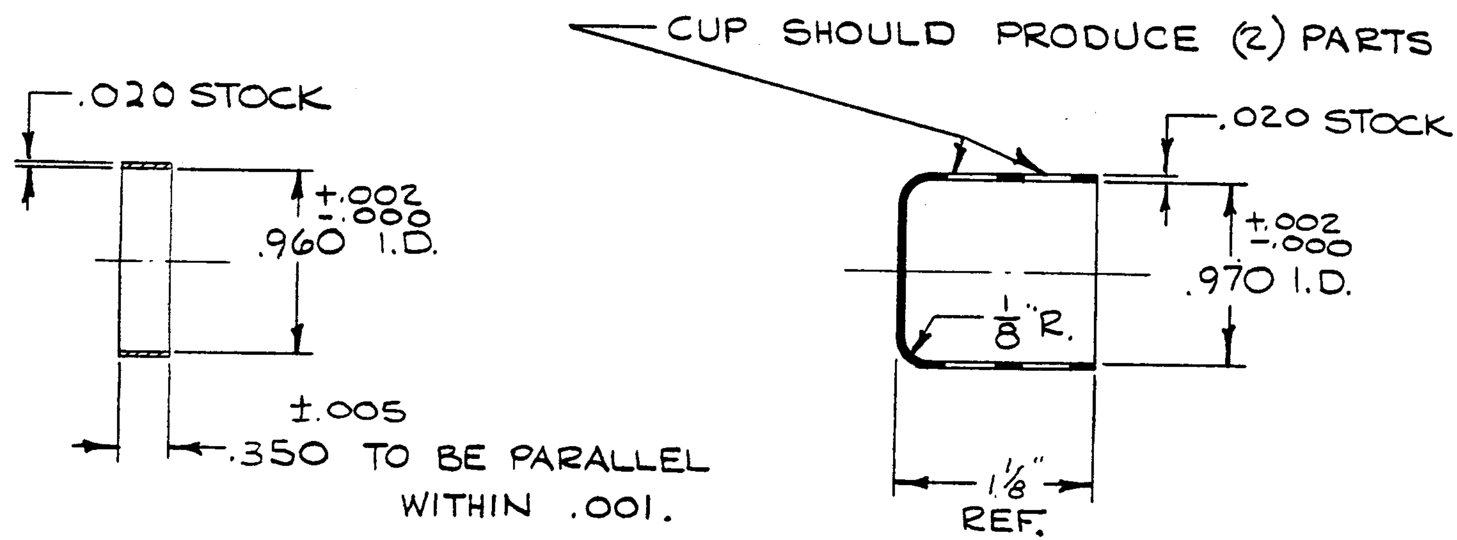


NOTES:

1. PLANE OF ENDS TO BE PARALLEL WITHIN .001.
2. WASH WG12 ALL PARTS
3. BRAZE - COPPER
4. VACUUM
5. TEMPERATURE - 1100°C

INSULATOR ASSEMBLY

344-2103

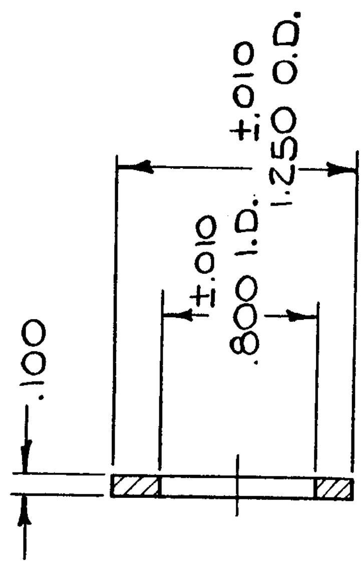


NOTES:

1. WASH W612.
2. FIRE DRY H_2, 1020°C, FOR (10) MINS.
3. DULL NICKEL PLATE .0001-.0002, ALL OVER.
4. FIRE LINE H_2, 1020°C, FOR (10) MINS.
5. STORE IN CLEAN CONTAINER.

ISOLATION RING, SMALL

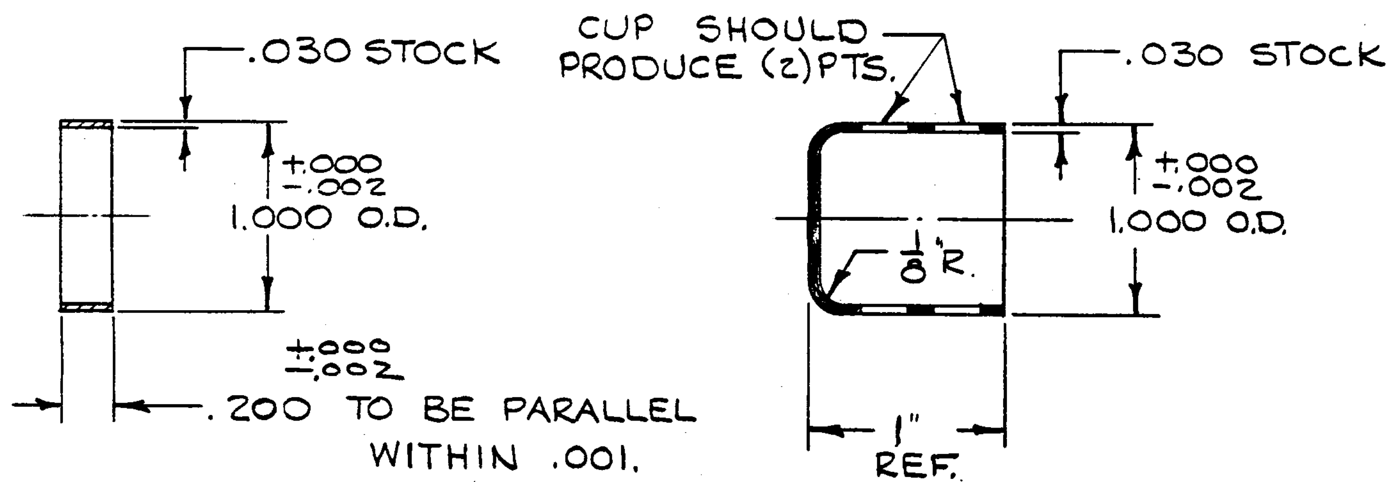
344-2037



NOTE: METALIZE FULL (BOTH SIDES).

CERAMIC INSULATOR

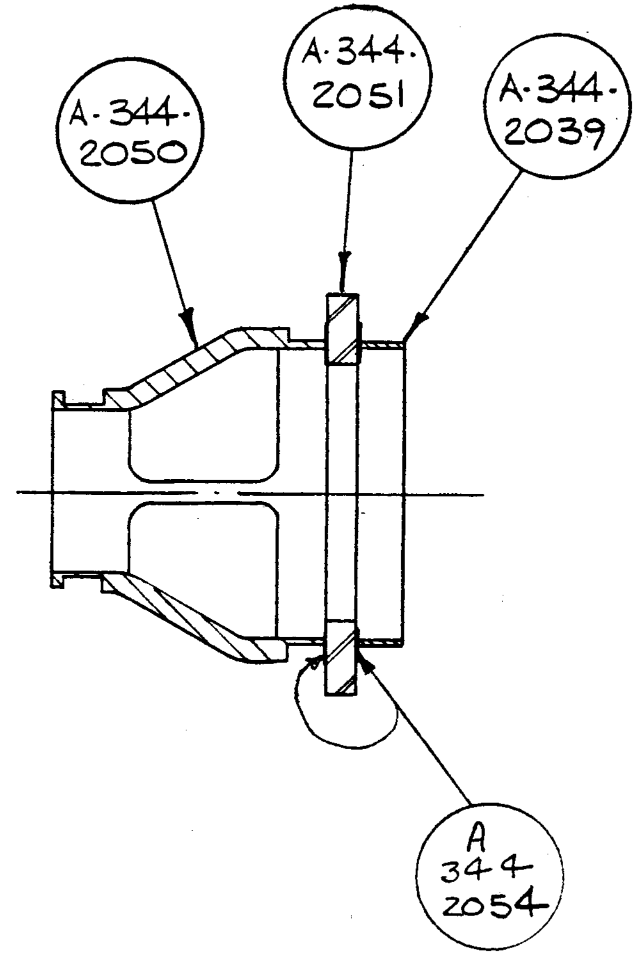
344-2043



NOTES:
1. WASH W612.
2. FIRE DRY H_2, 1020°C, FOR (10) MINS.
3. DULL NICKEL PLATE .0001-.0002 ALL OVER.
4. FIRE LINE H_2, 1020°C, FOR (10) MINS.
5. STORE IN CLEAN CONTAINER.

STRAIN ISOLATION RING

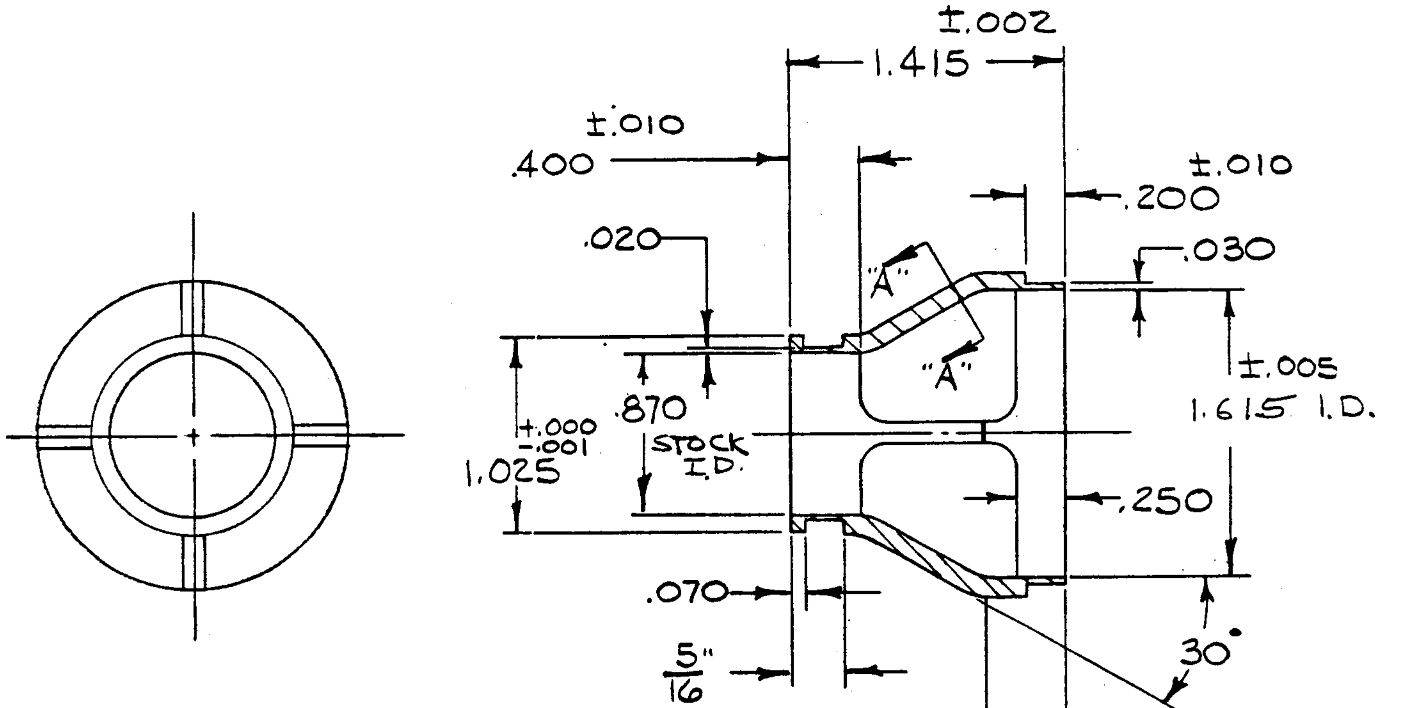
344-2038

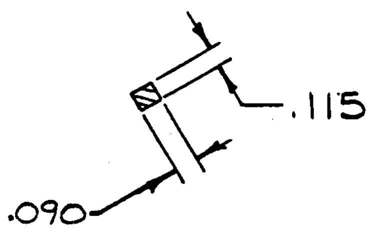


BRAZE - COPPER
FURNACE - HYDROGEN
TIME AT TEMP. (   )
TEMPERATURE - 1100°C.

GENERATOR SUPPORT RING ASSEMBLY

344-2049





SECTION "A"-"A"

SEQUENCE:

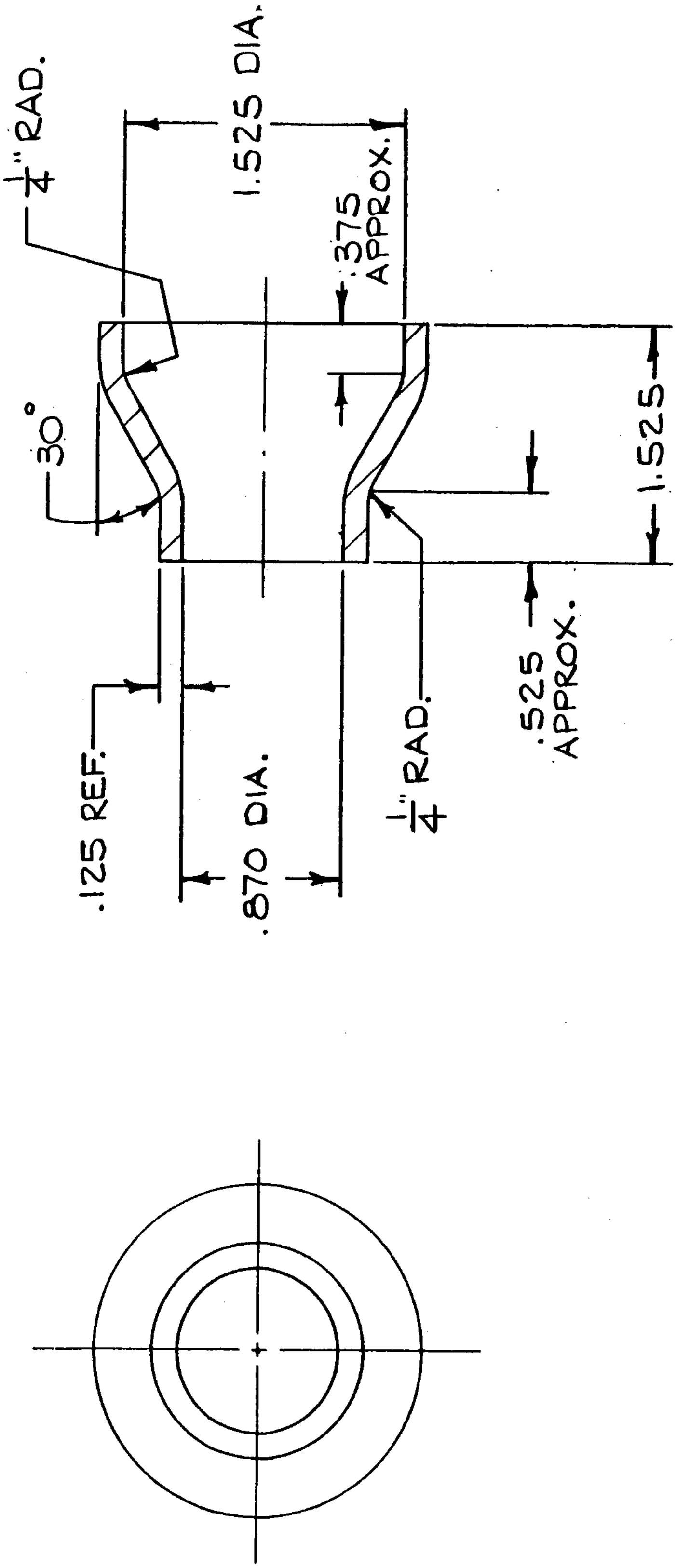
1. INDICATE ON I.D.
2. FACE .010" TO .015" OFF LARGE END.
3. HOLD 1.415 BY FACING REMAINING MATERIAL OFF SMALL END.
4. FINISH MACHINE.

NOTES:

1. ALL RADII TO BE APPROX. 1"/8.
2. WASH W612.
3. STORE IN CLEAN CONTAINER.

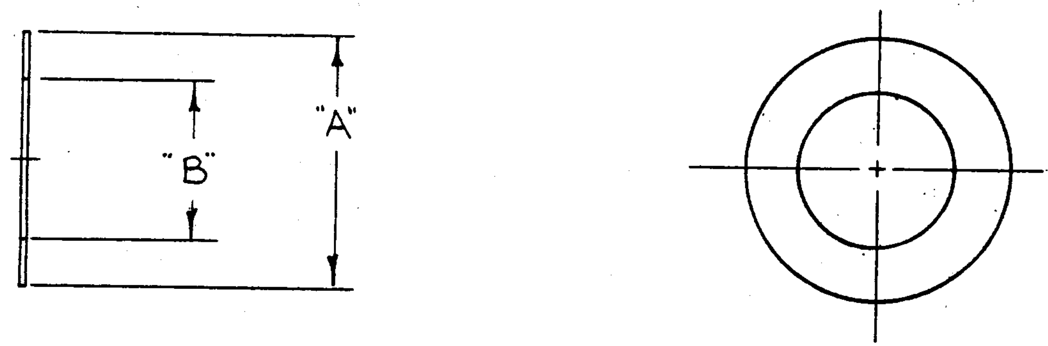
GENERATOR SUPPORT RING

344-2050



GENERATOR SUPPORT RING BLANK
344-2099

NOTES:
1. FIRE - HYDROGEN 1000°C TO STRESS RELIEVE.



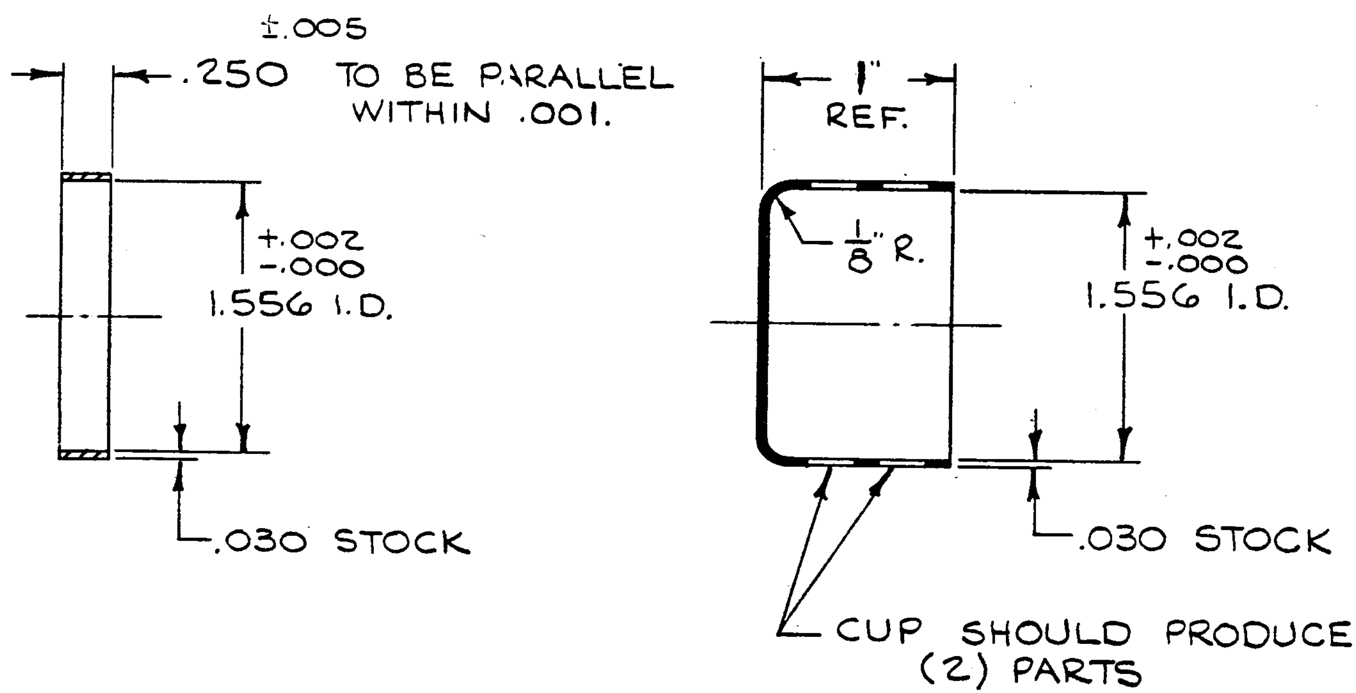
PT.	"A"	"B"	TOOL #
2	2.100 ± 005	1.355 ±.005	37000- T8-29-1
1	1.250 ±.005	.800 ±.005	37000- T8-29-2

NOTES:

1. WASH W612.
2. RINSE WITH ACETONE.
3. STORE WRAPPED IN KIMWIPES.

SOLDER WASHER

344-2054

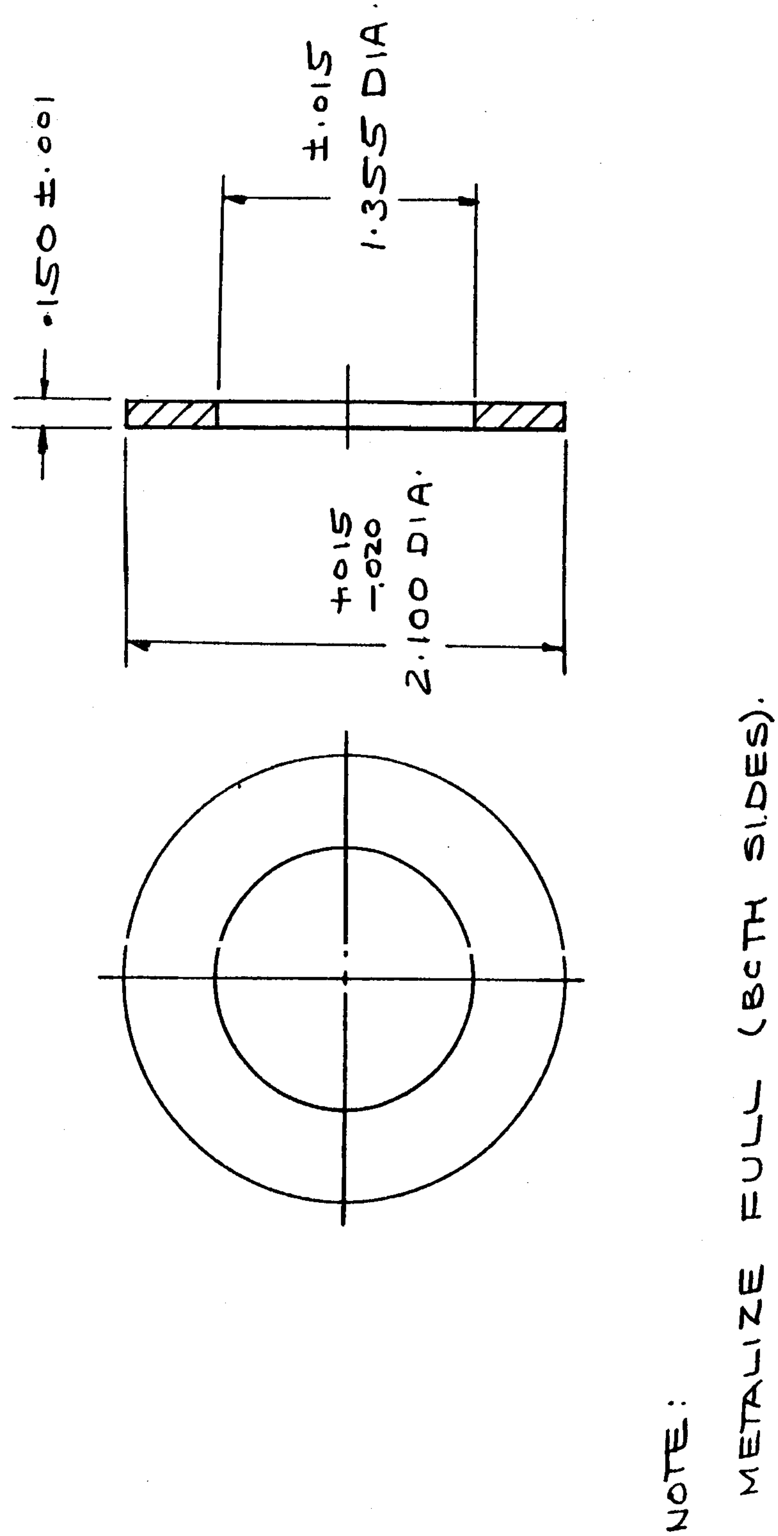


NOTES:

1. WASH W612.
2. FIRE DRY H_2, 1020°C, FOR (10) MINS.
3. DULL NICKEL PLATE .0001-.0002 ALL OVER.
4. FIRE LINE H_2, 1020°C, FOR (10) MINS.

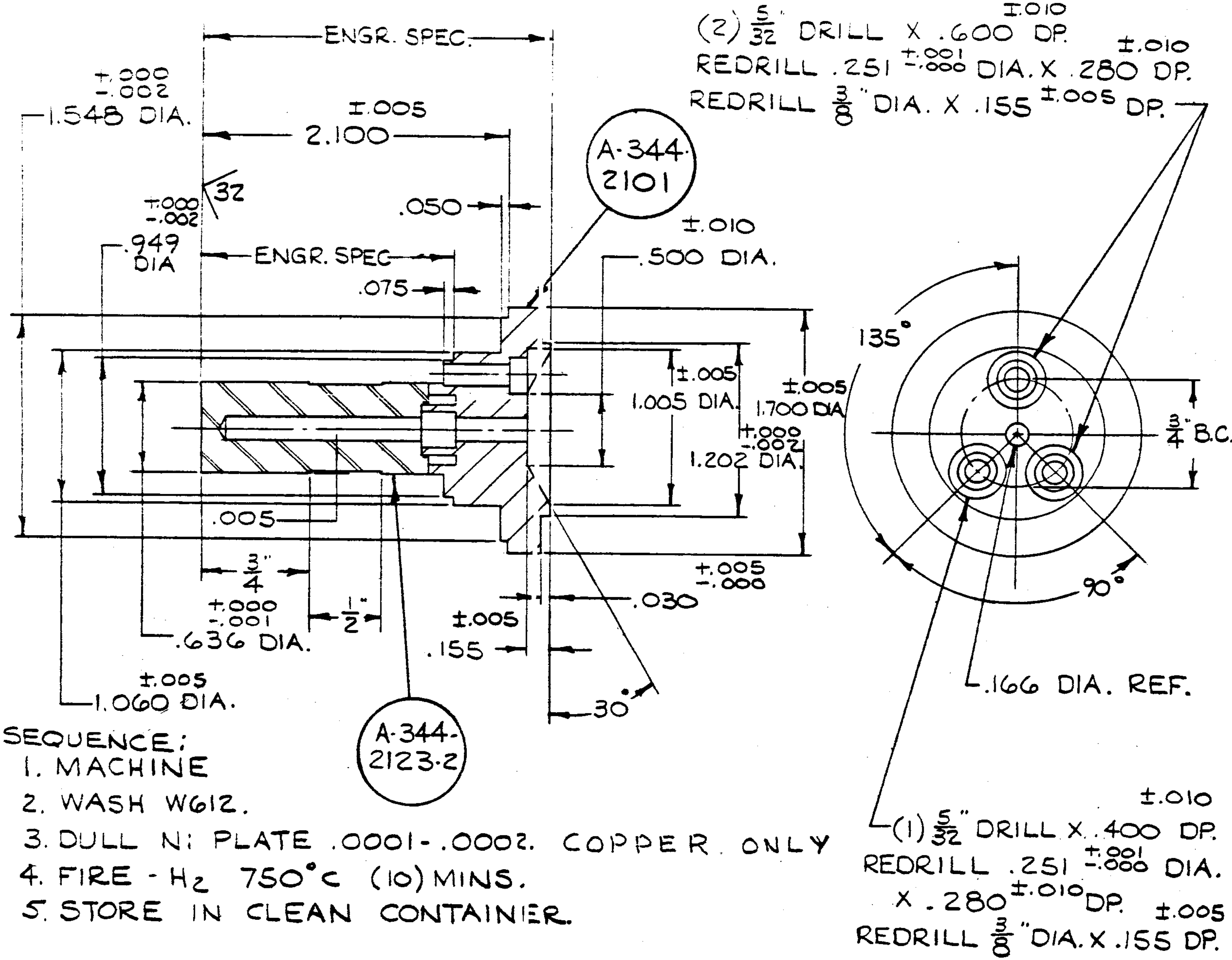
STRAIN ISOLATION RING, LARGE

344-2039



CERAMIC INSULATOR

344-2051

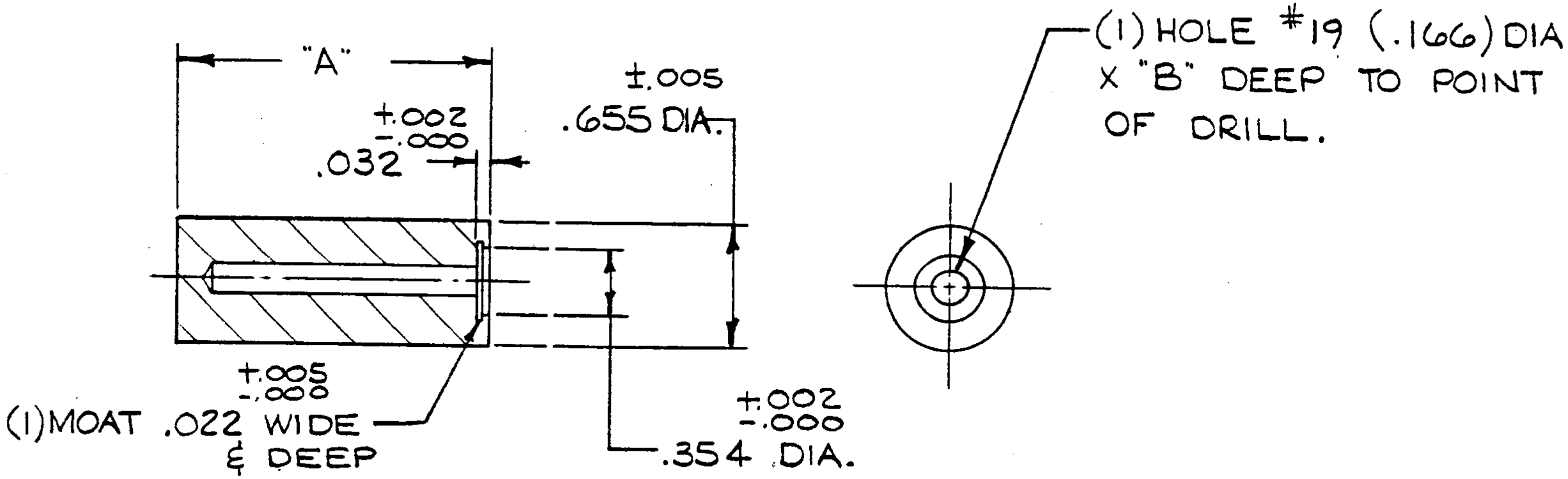


SEQUENCE:
1. MACHINE
2. WASH W612.
3. DULL Ni PLATE .0001-.0002. COPPER ONLY
4. FIRE - H_2 750°C (10) MINS.
5. STORE IN CLEAN CONTAINER.

COLLECTOR ASSEMBLY - 344-2271

SEQUENCE:

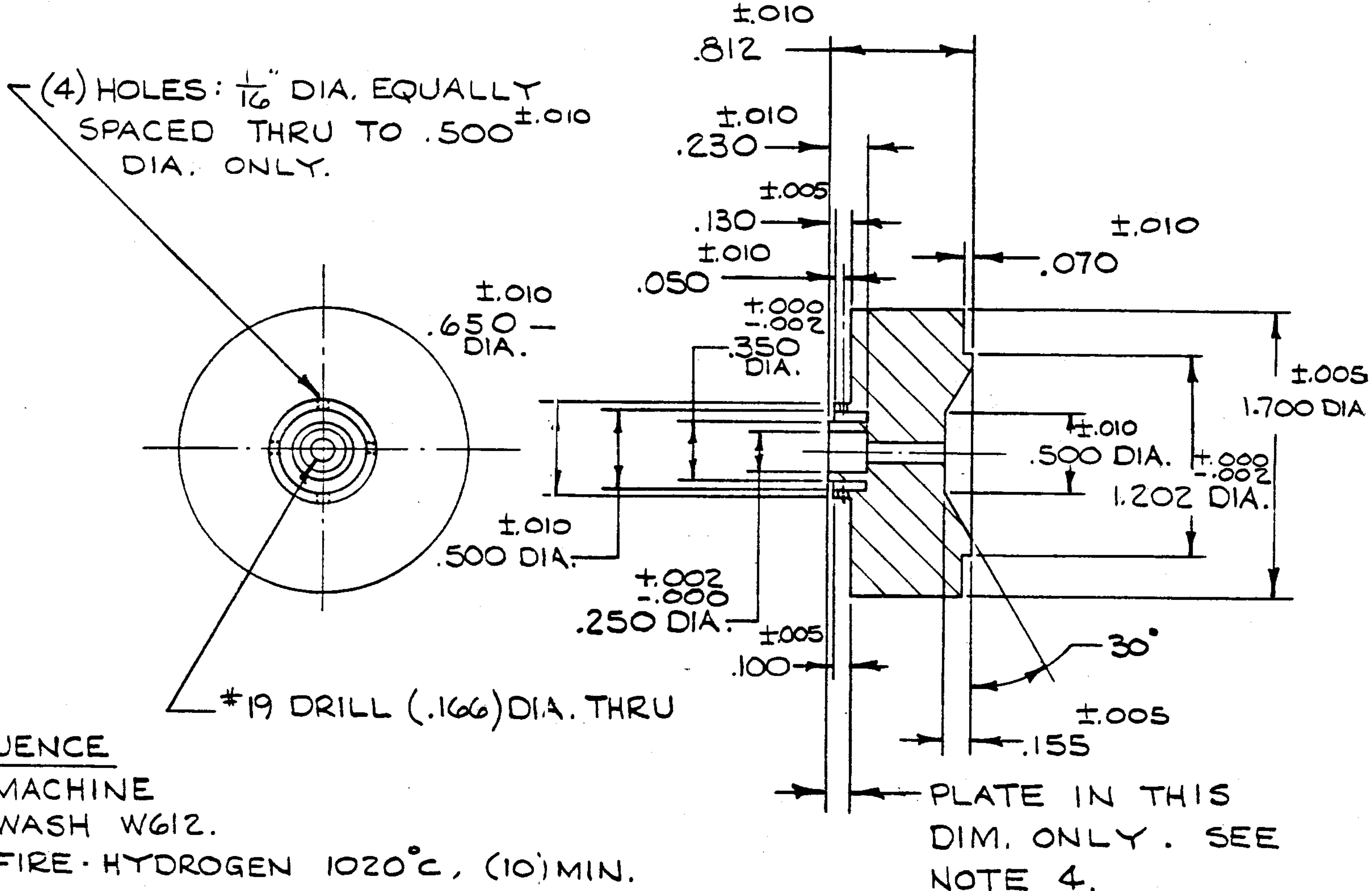
1. MACHINE
2. WASH - W612.
3. FIRE - VACUUM 1200° TO 1500°C (5) MIN.
4. STORE IN CLEAN CONTAINER.



PT.	"A"	"B"	CATH. MAT'L.
1.	1.550 ±.003	1 3/8"	MOLY
2.	1.600 ±.003	1 3/8"	TANTALUM

COLLECTOR HEAD

344-2123

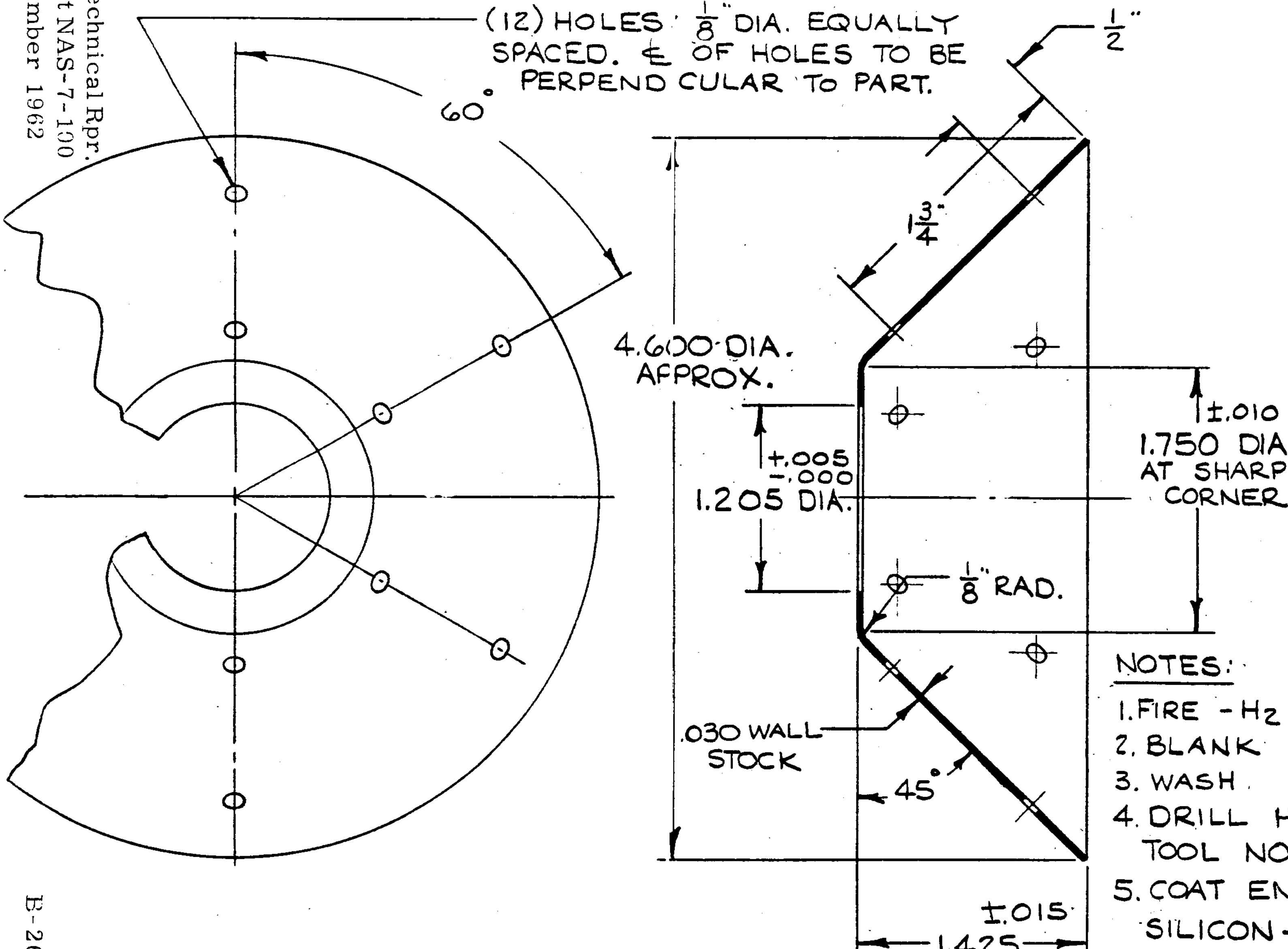


SEQUENCE

1. MACHINE
2. WASH W612.
3. FIRE - HYDROGEN 1020°C, (10) MIN.
4. PLATE - DULL Ni .0002 - .0005 THK.
5. FIRE - SAME AS NOTE 3.
6. STORE IN CLEAN CONTAINER.

COLLECTOR BASE

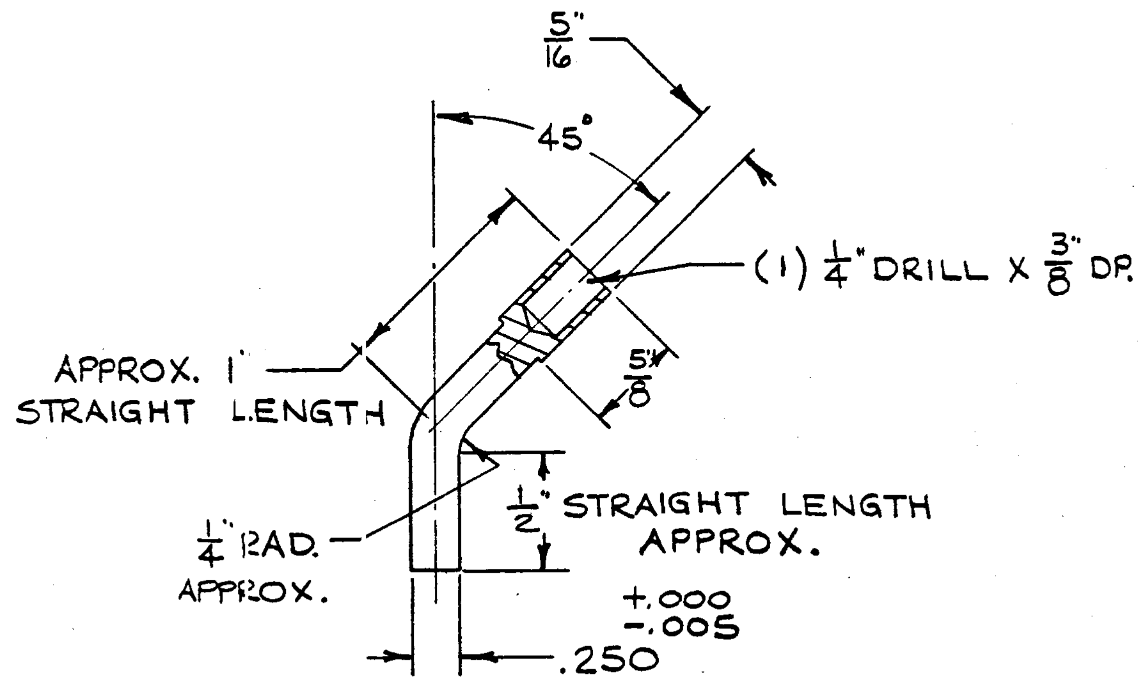
344-2101



NOTES:

1. FIRE - H_2 830°C, (10) MIN.
2. BLANK
3. WASH
4. DRILL HOLES USING TOOL NO. 37000-14-29.
5. COAT ENTIRE PART WITH SILICON-ALUMINUM.
6. BAKE 850°C, (15) MIN.

COLLECTOR RADIATOR FIN
344-2100

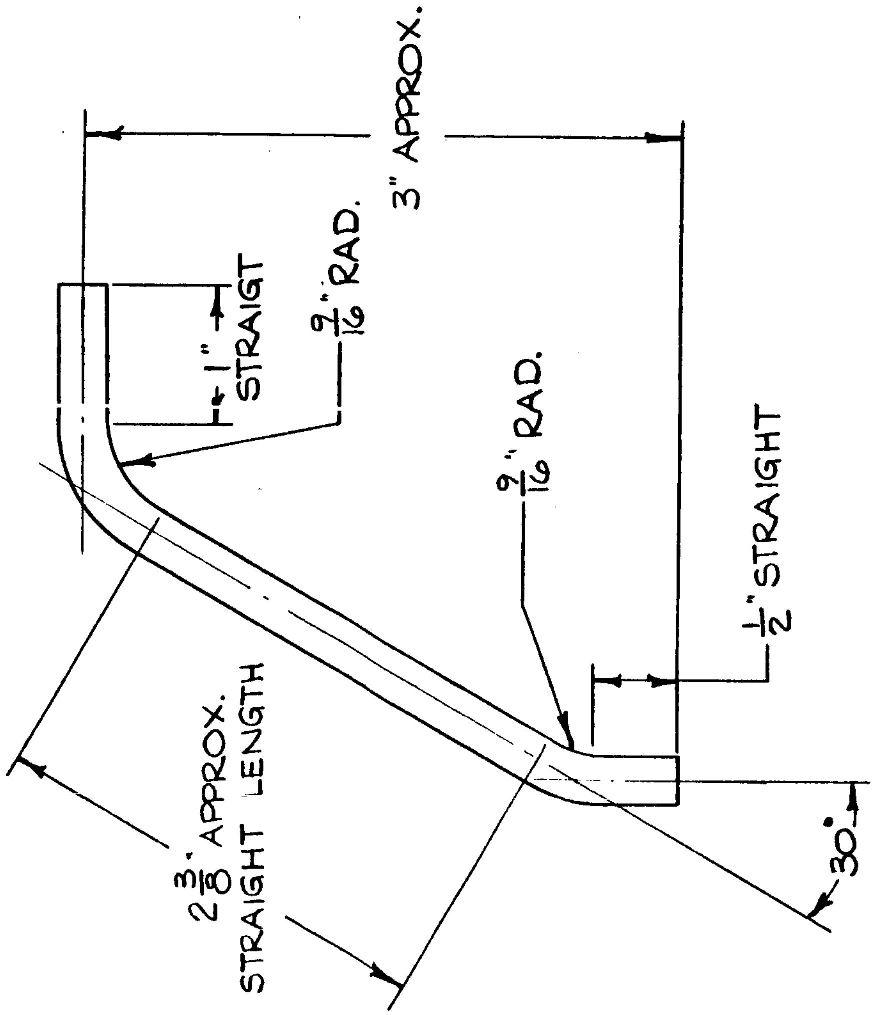


NOTES:

1. WASH W612.
2. FIRE IN DRY OR LINE H_2 1020°C, FOR (5) MINS.

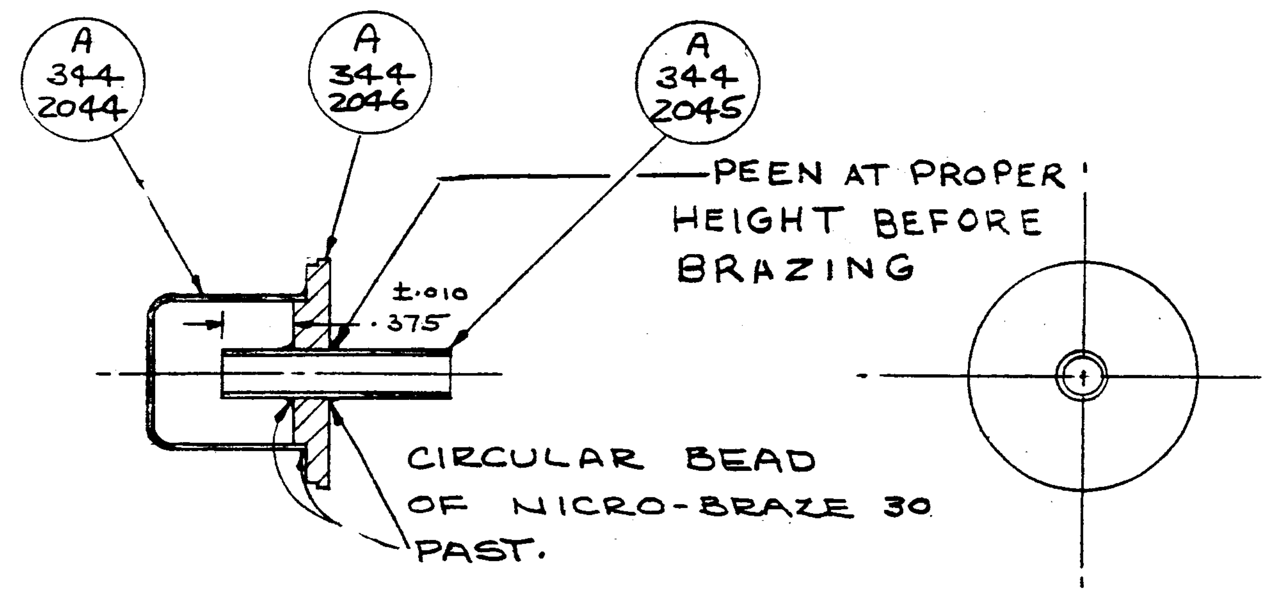
COLLECTOR LEAD

344-2055



EXHAUST LINE TUBING

344-2122

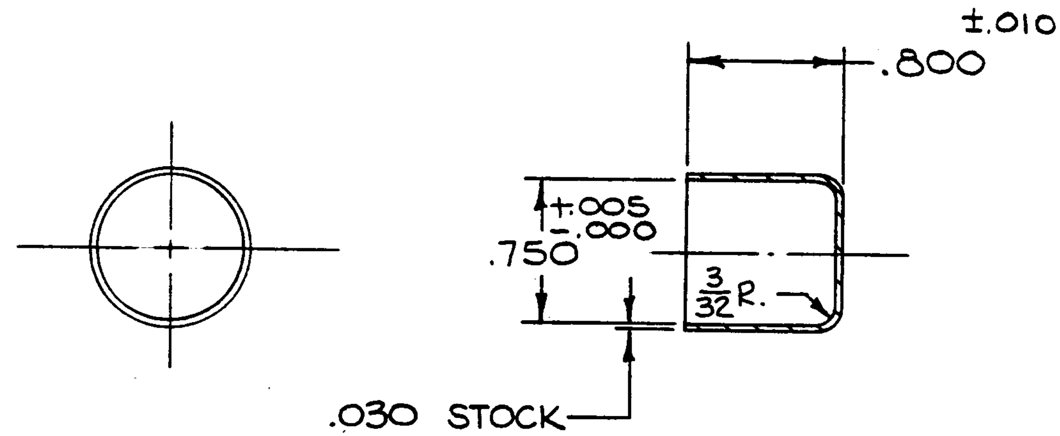


BRAZE - NICRO BRAZE 30.
FURNACE - VACUUM.
TIME AT TEM. - ( )
TEMPERATURE - 1135°C

NOTE: MUST BE A VACUUM
TIGHT ASSY.

CESIUM RESERVOIR ASSEMBLY

344-2047

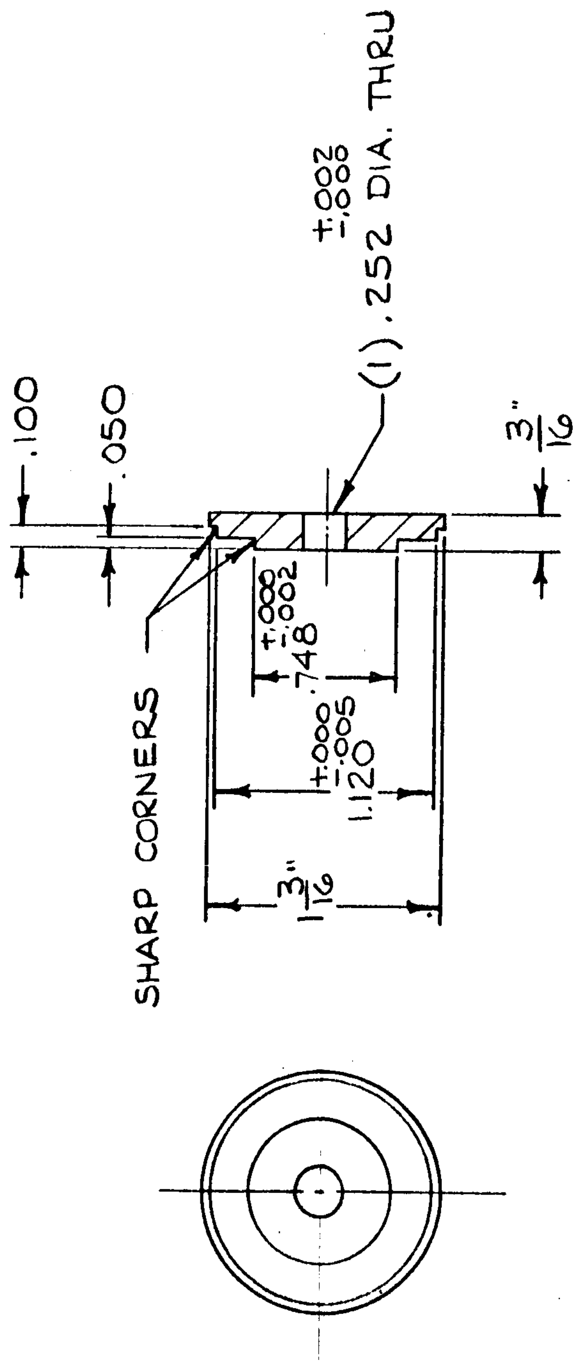


NOTES:

1. WASH W612.
2. FIRE DRY H_2, 1100°C, FOR (5) MINS.
3. STORE IN CLEAN CONTAINER.

CESIUM RESERVOIR CAP

344-2044

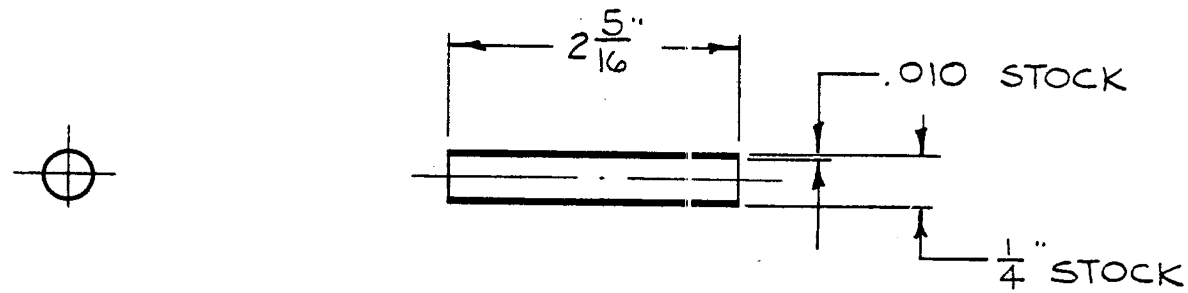


NOTES:

1. WASH WG12.
2. FIRE DRY H_2, 1100°C, FOR (5) MINS.
3. STORE IN CLEAN CONTAINER.

CESIUM RESERVOIR BASE

344-2046

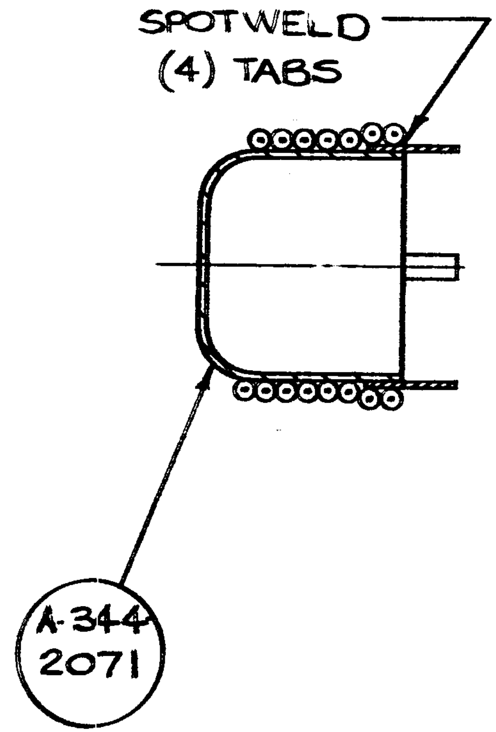


NOTES:

1. WASH W612.
2. STORE IN CLEAN CONTAINER.

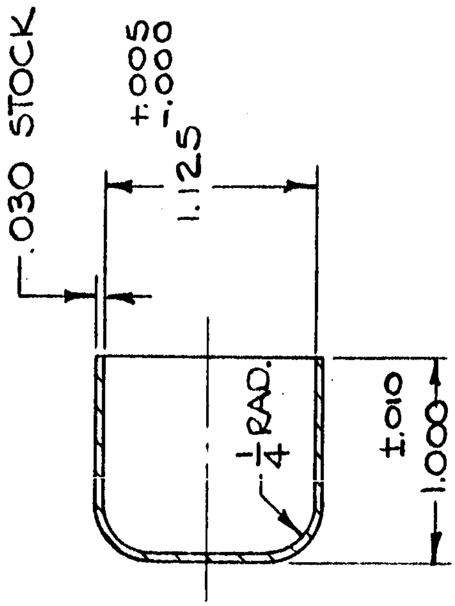
CESIUM RESERVOIR PIPE

344-2045



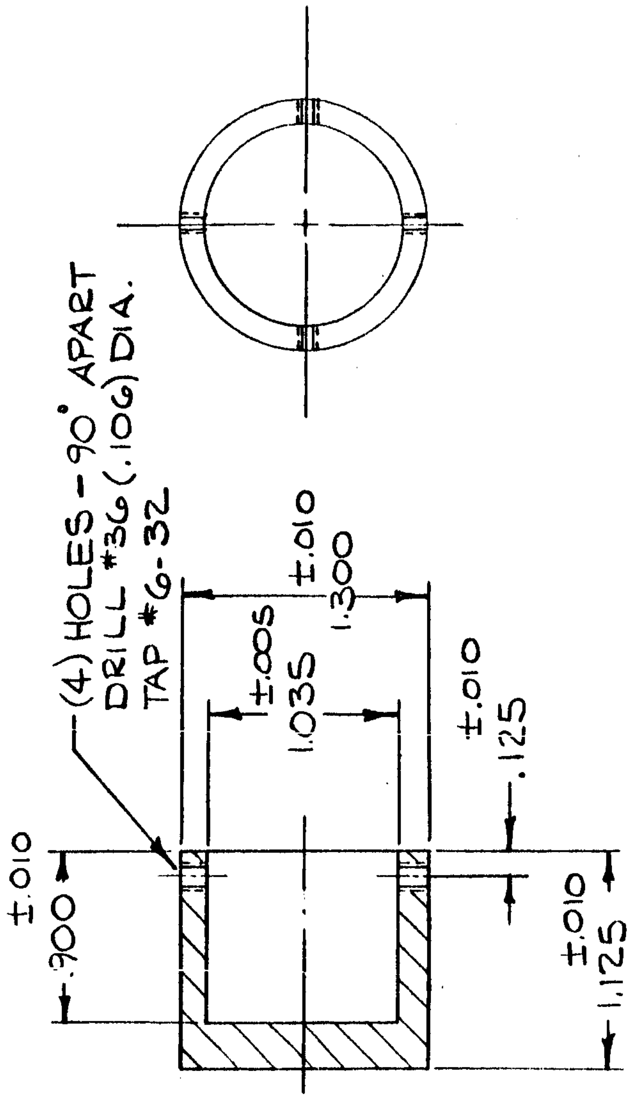
CESIUM RESERVOIR HEATER ASSEMBLY

344-2058



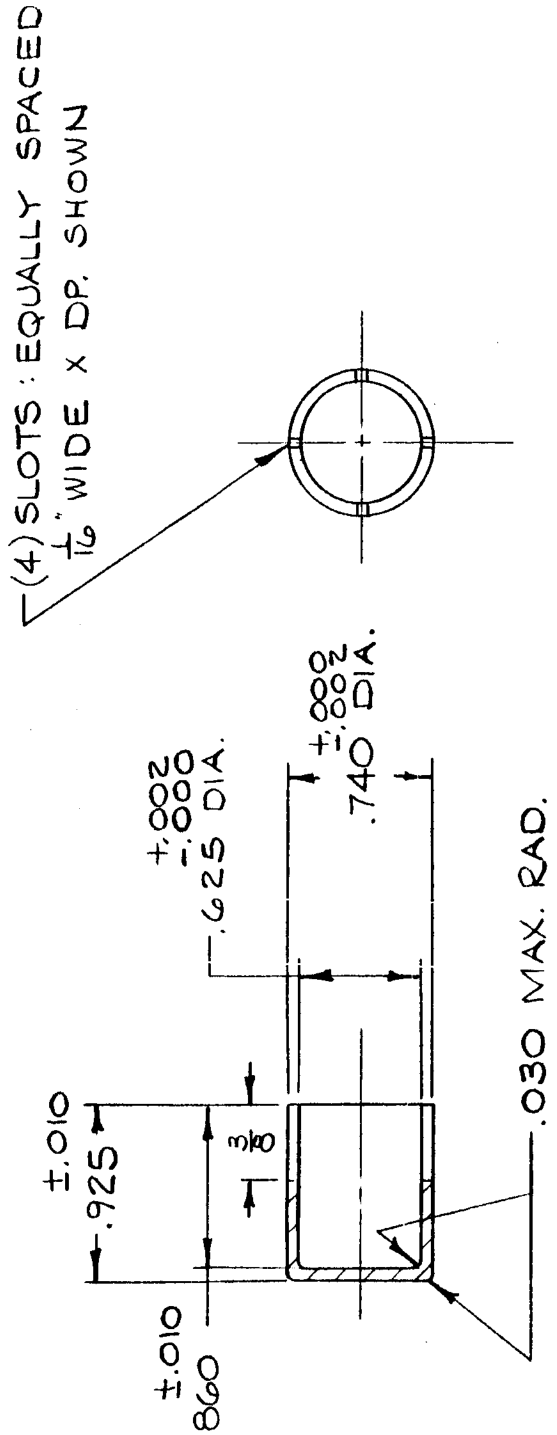
CESIUM RESERVOIR HEATER CAP

344-2071



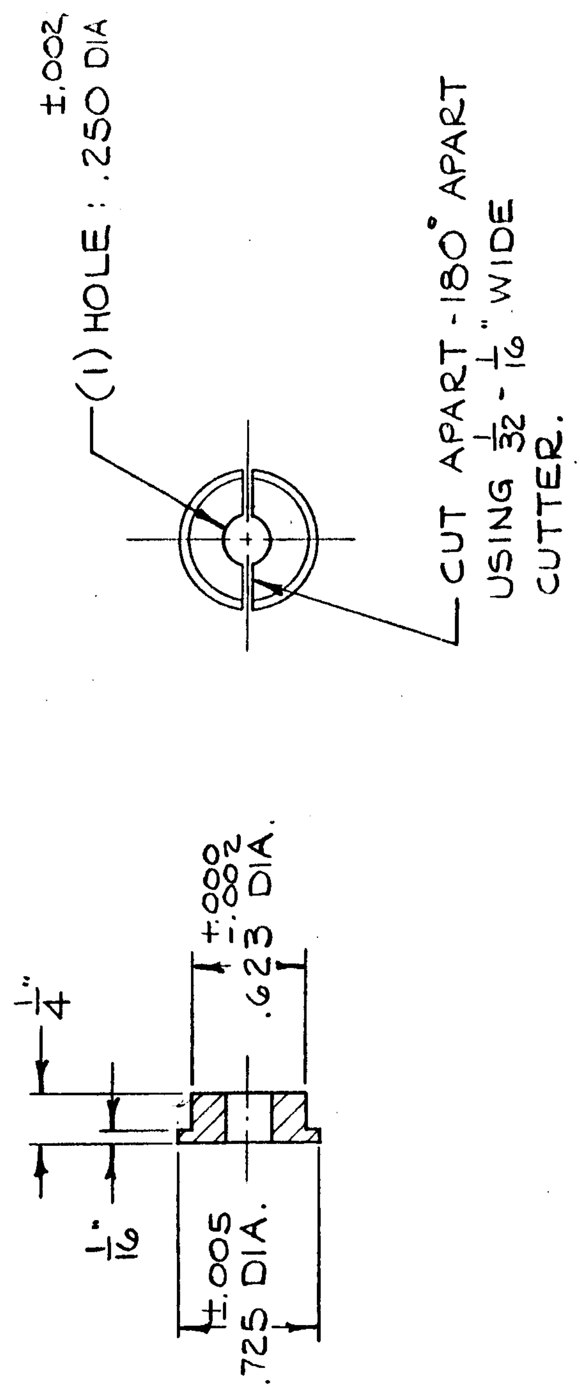
EMITTER SHIELD

344-2270



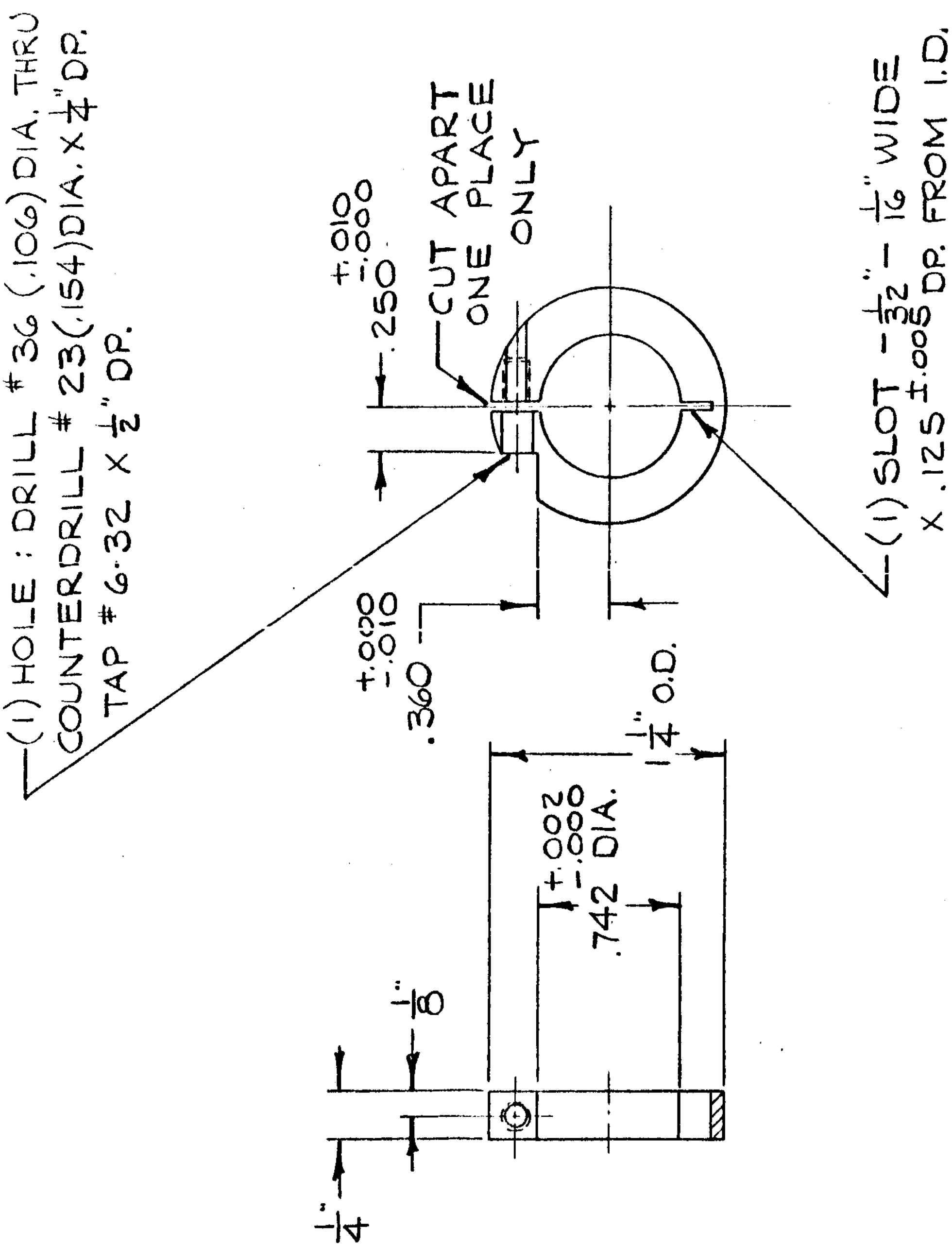
PINCH-OFF PROTECTOR SLEEVE

344-2225



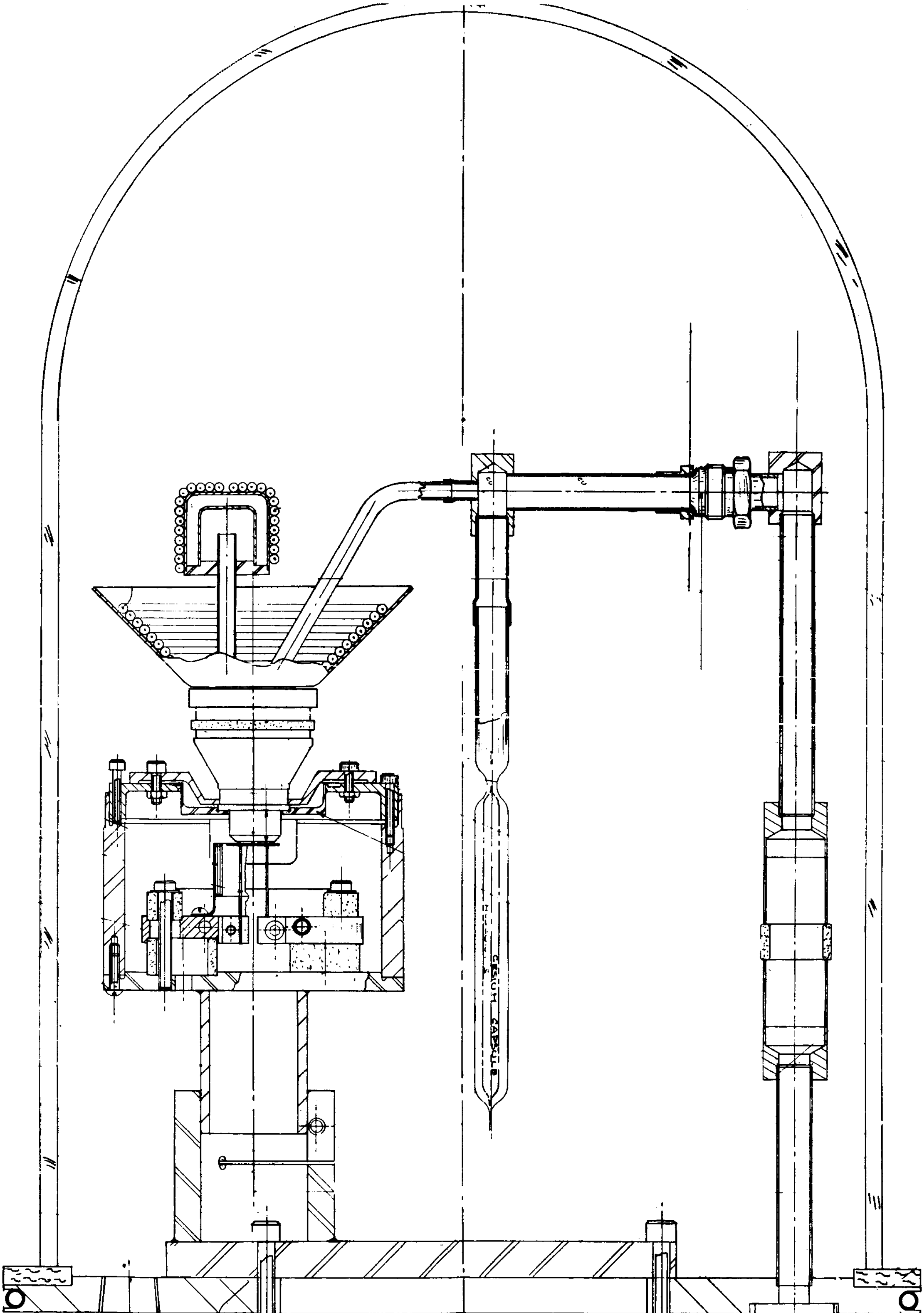
PINCH-OFF PROTECTOR SPLIT RING

344-2226

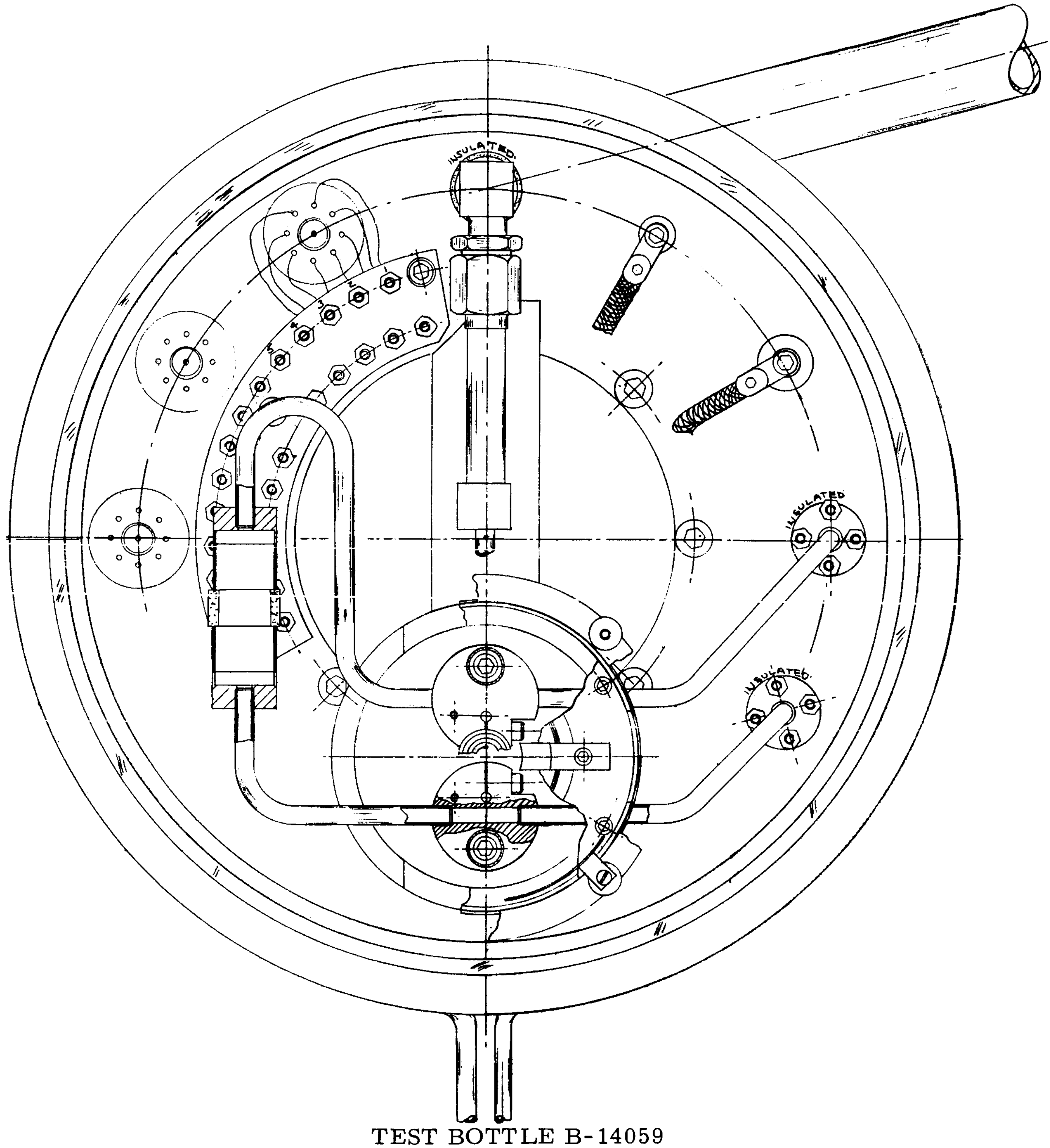


PINCH-OFF PROTECTOR CLAMPING RING

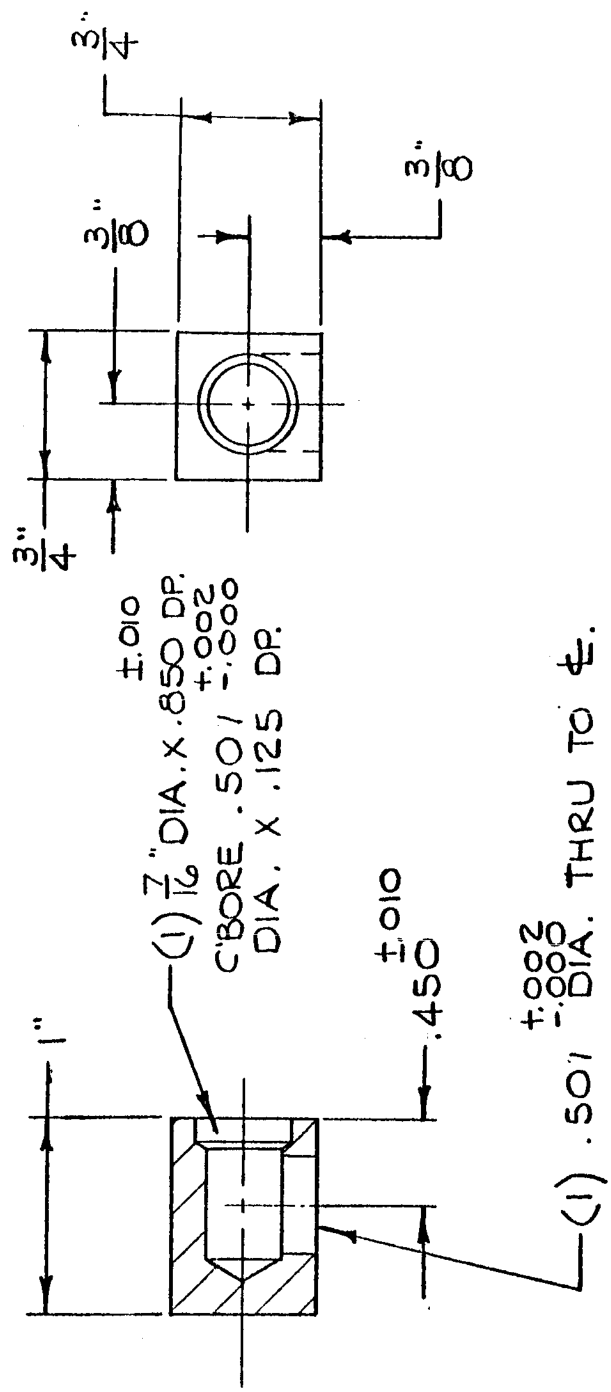
344-2227



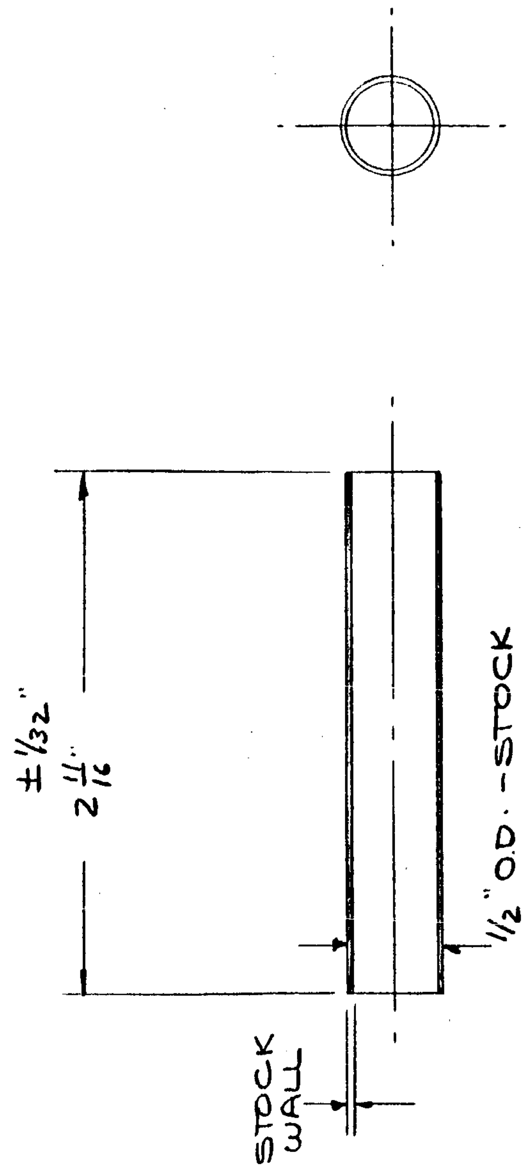
TEST BOTTLE A-14059



TEST BOTTLE B-14059

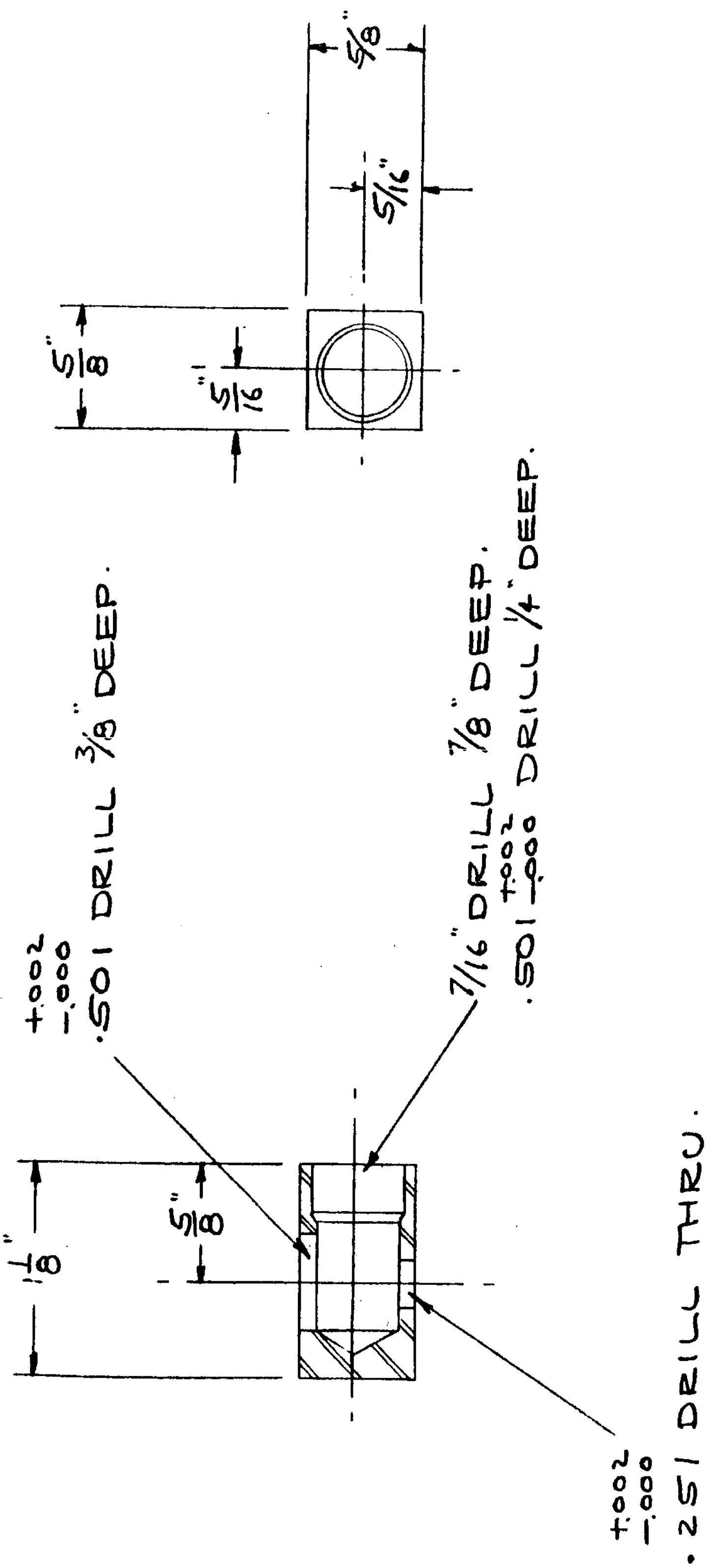


CONNECTOR
14060

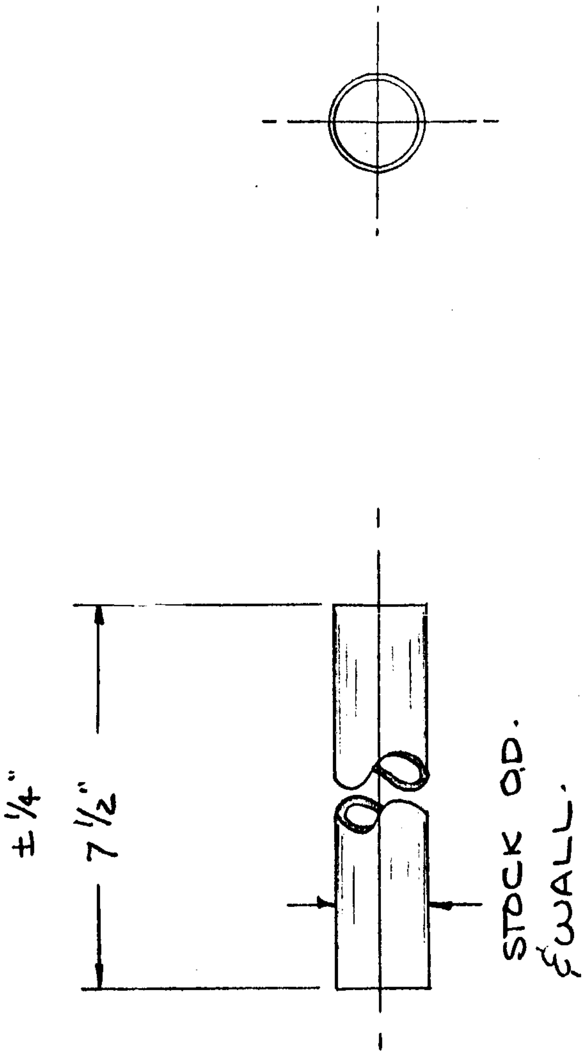


EXHAUST TUBING

14061

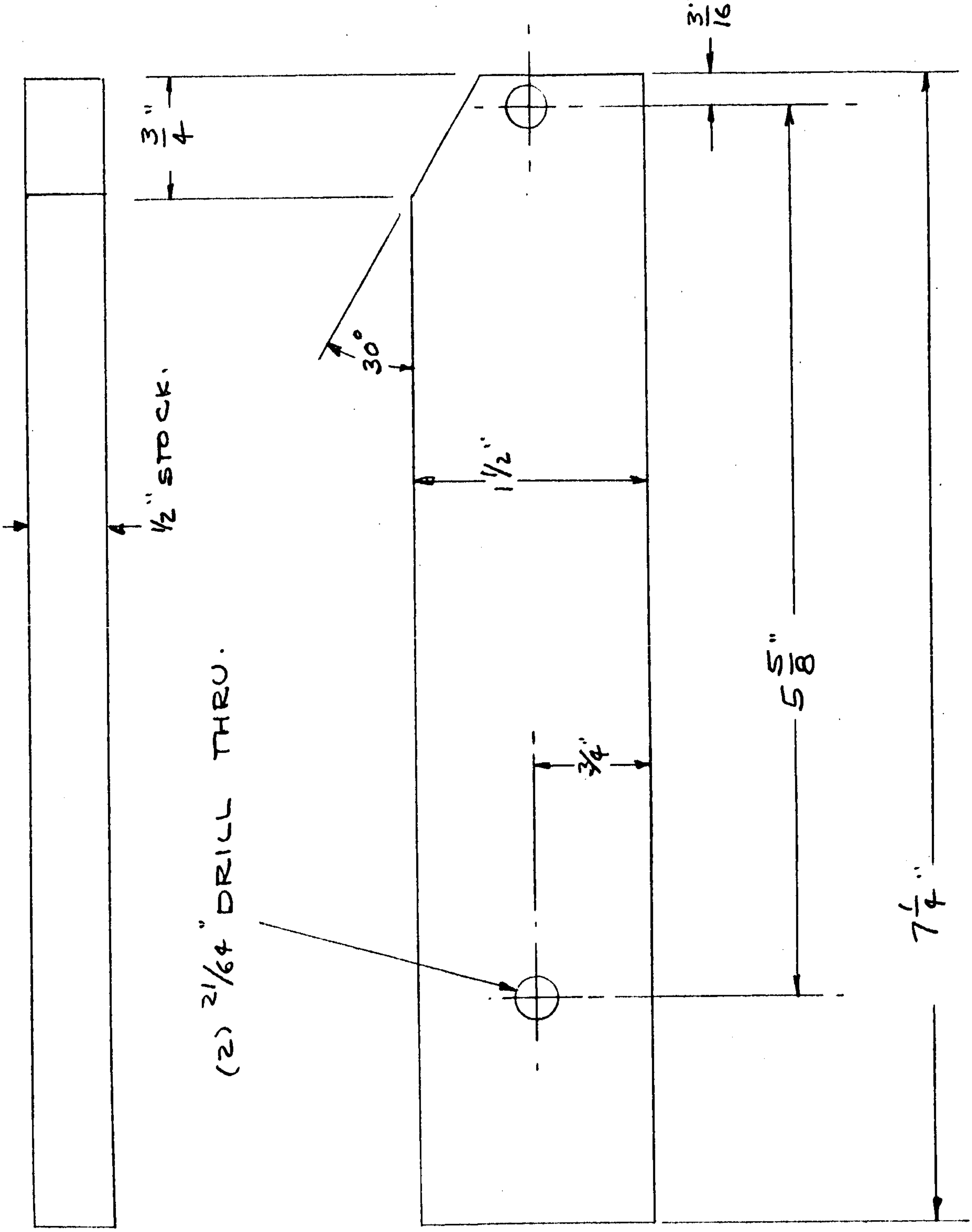


EXHAUST JOINT
14062



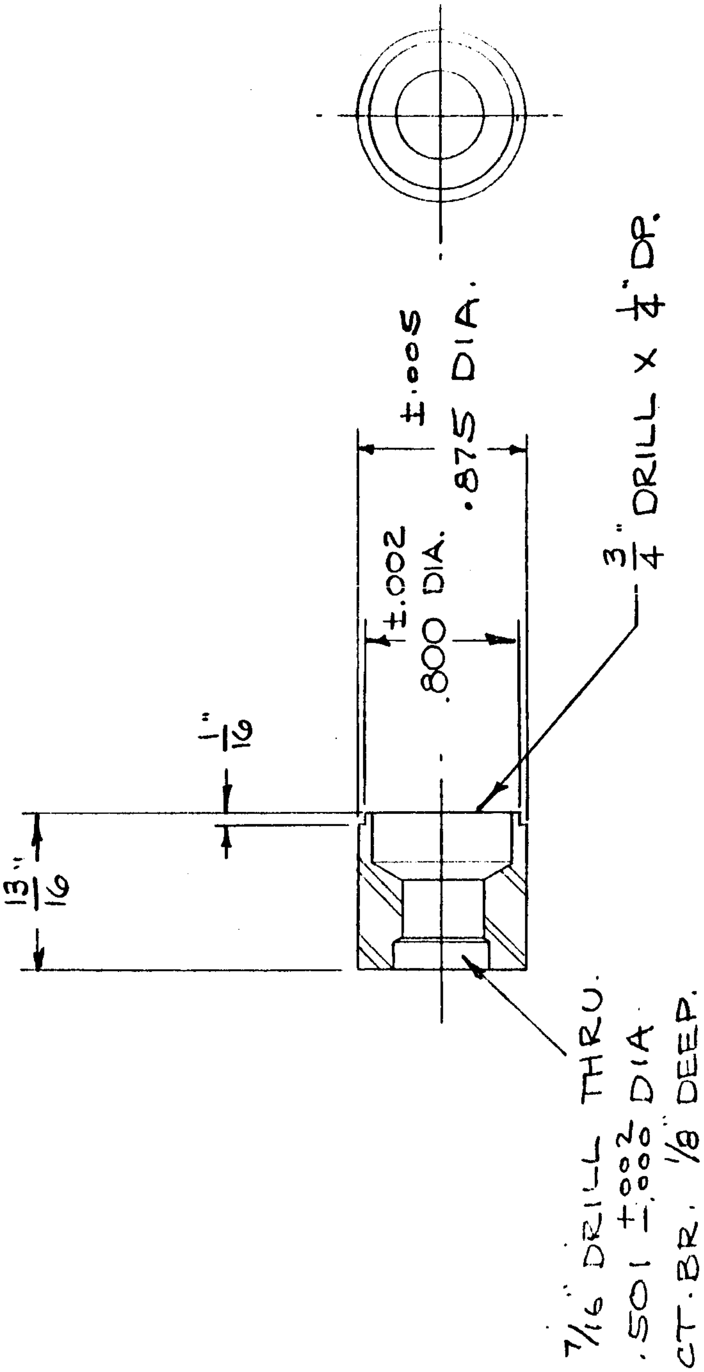
CESIUM TUBING

14063



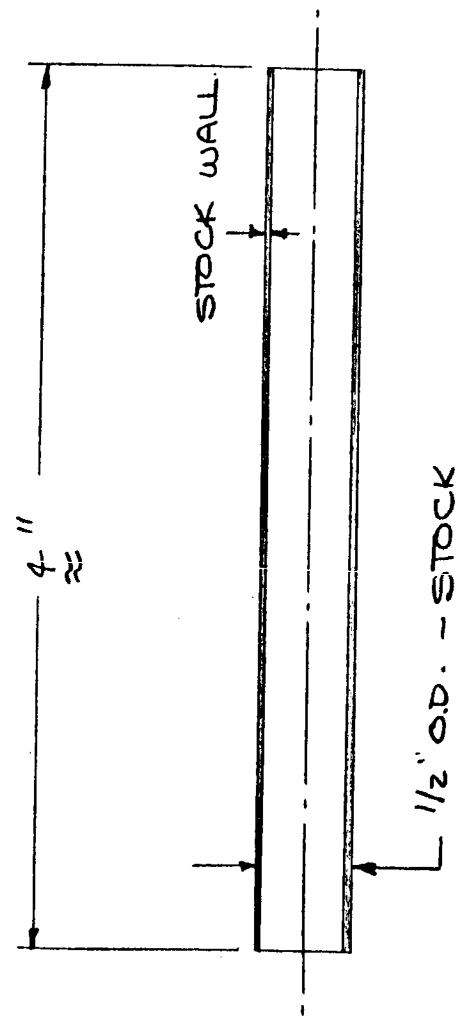
MOUNT BAR

14064



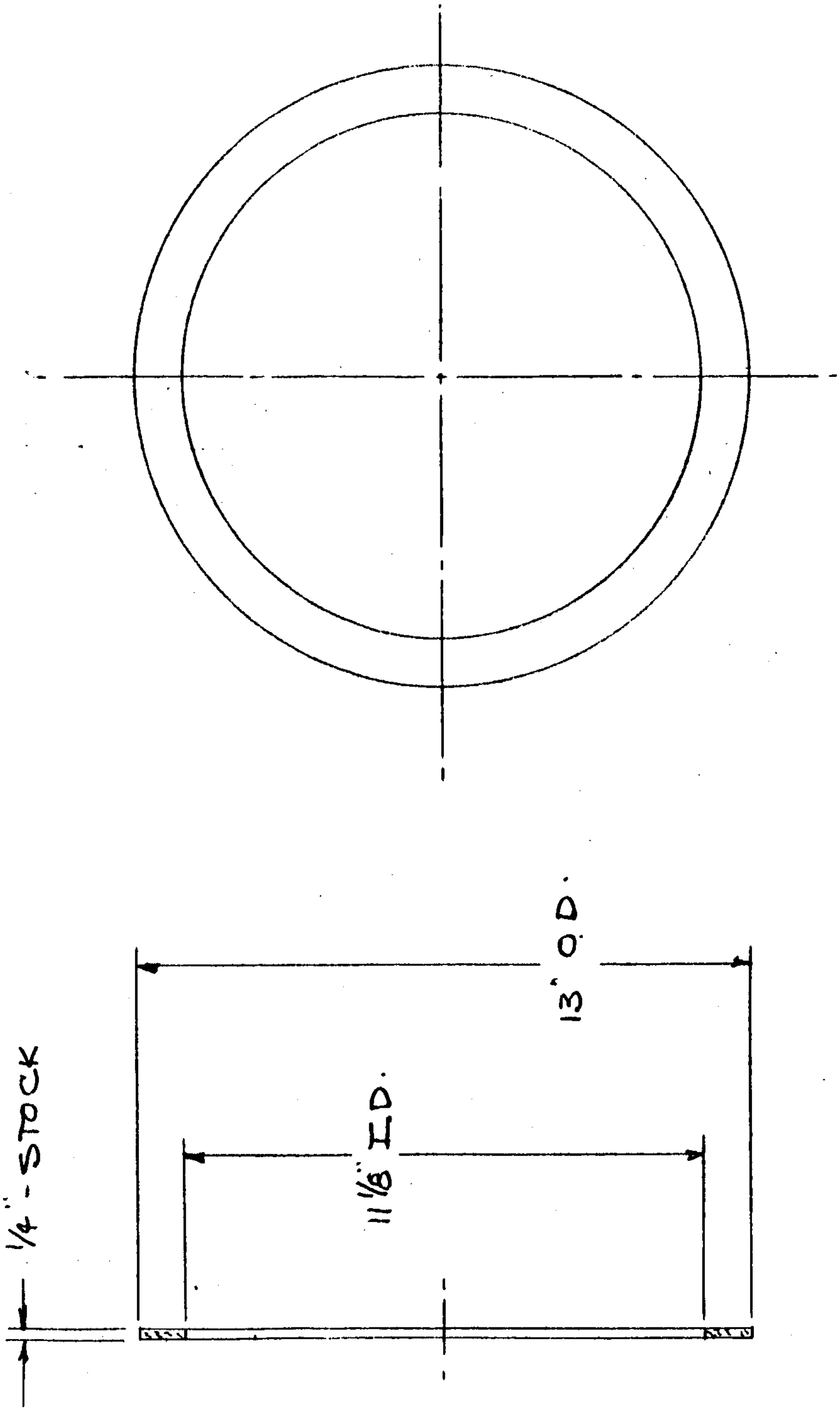
INSULATOR ADAPTOR

14065

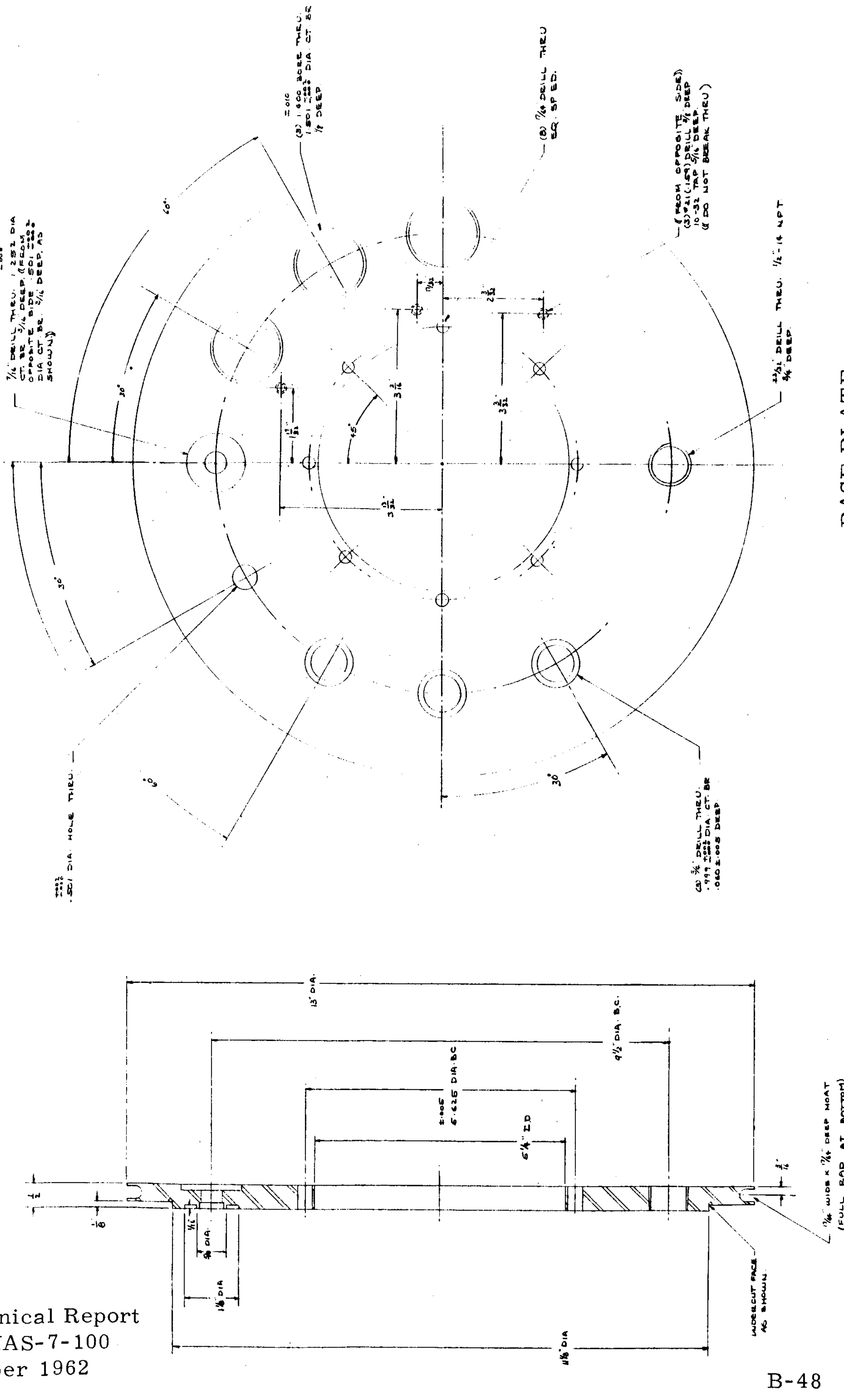


EXHAUST LINE

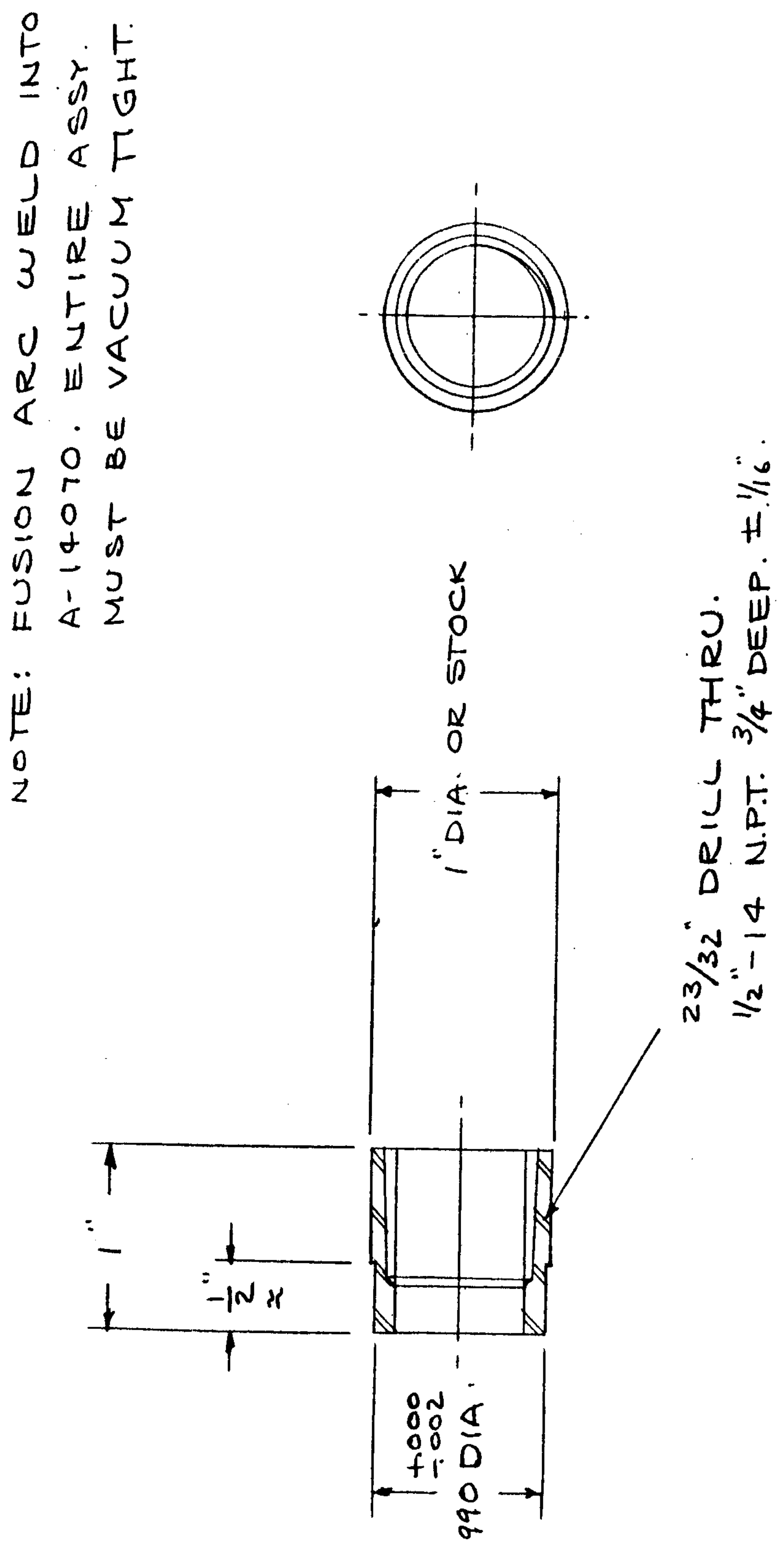
14066



BOTTLE GASKET
14067

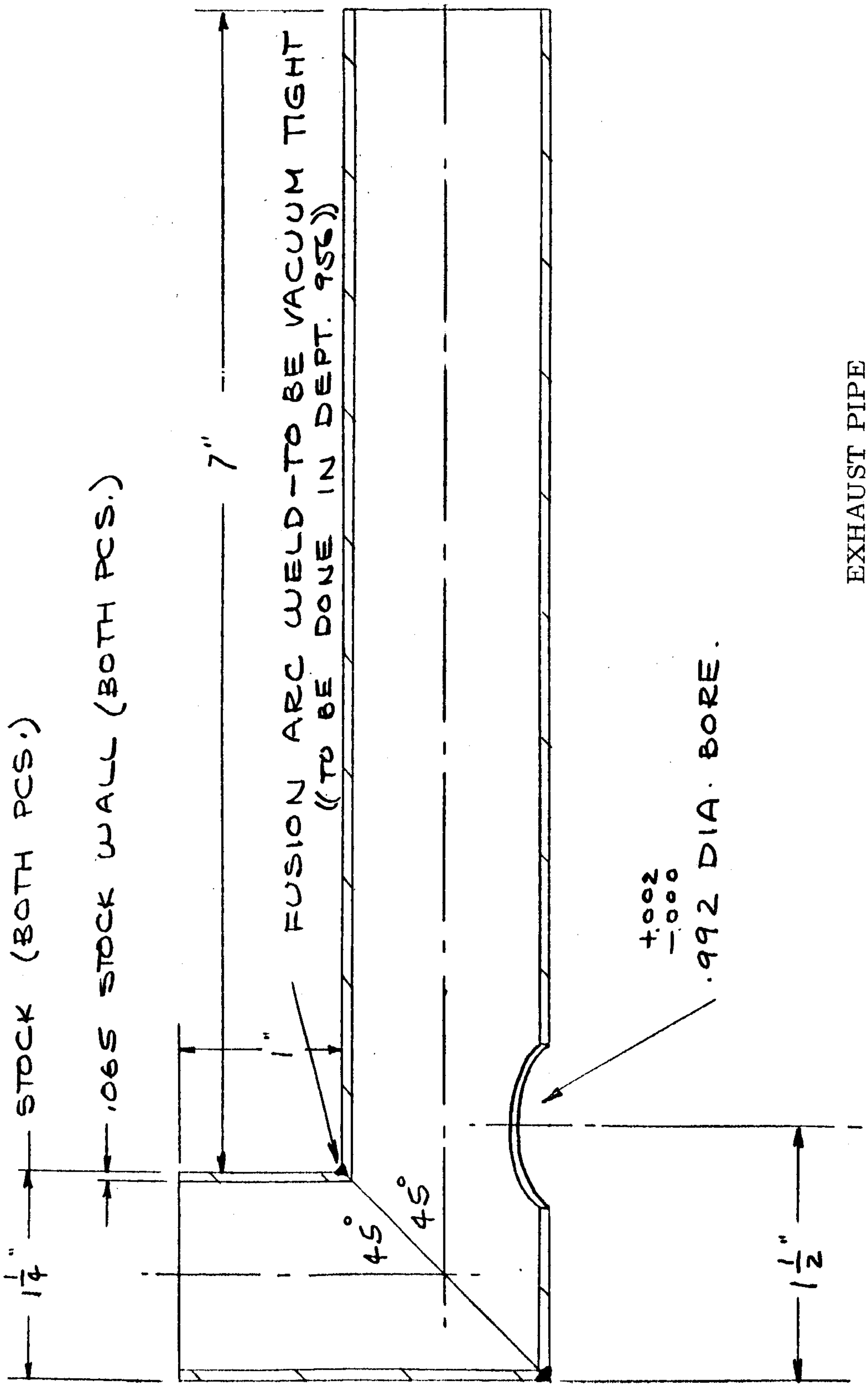


BASE PLATE
14068



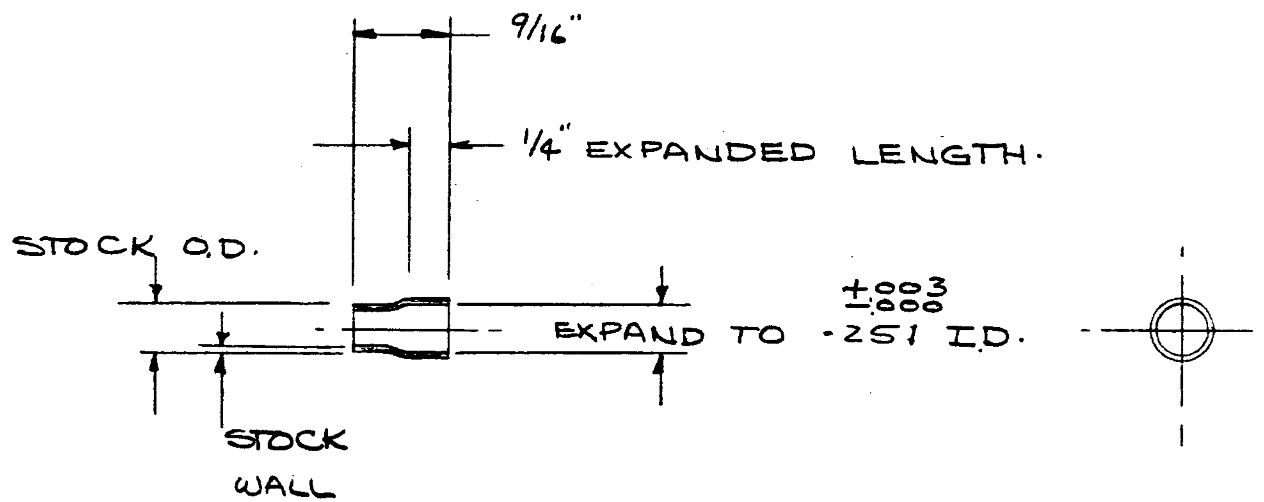
ION GAUGE ADAPTOR

14069



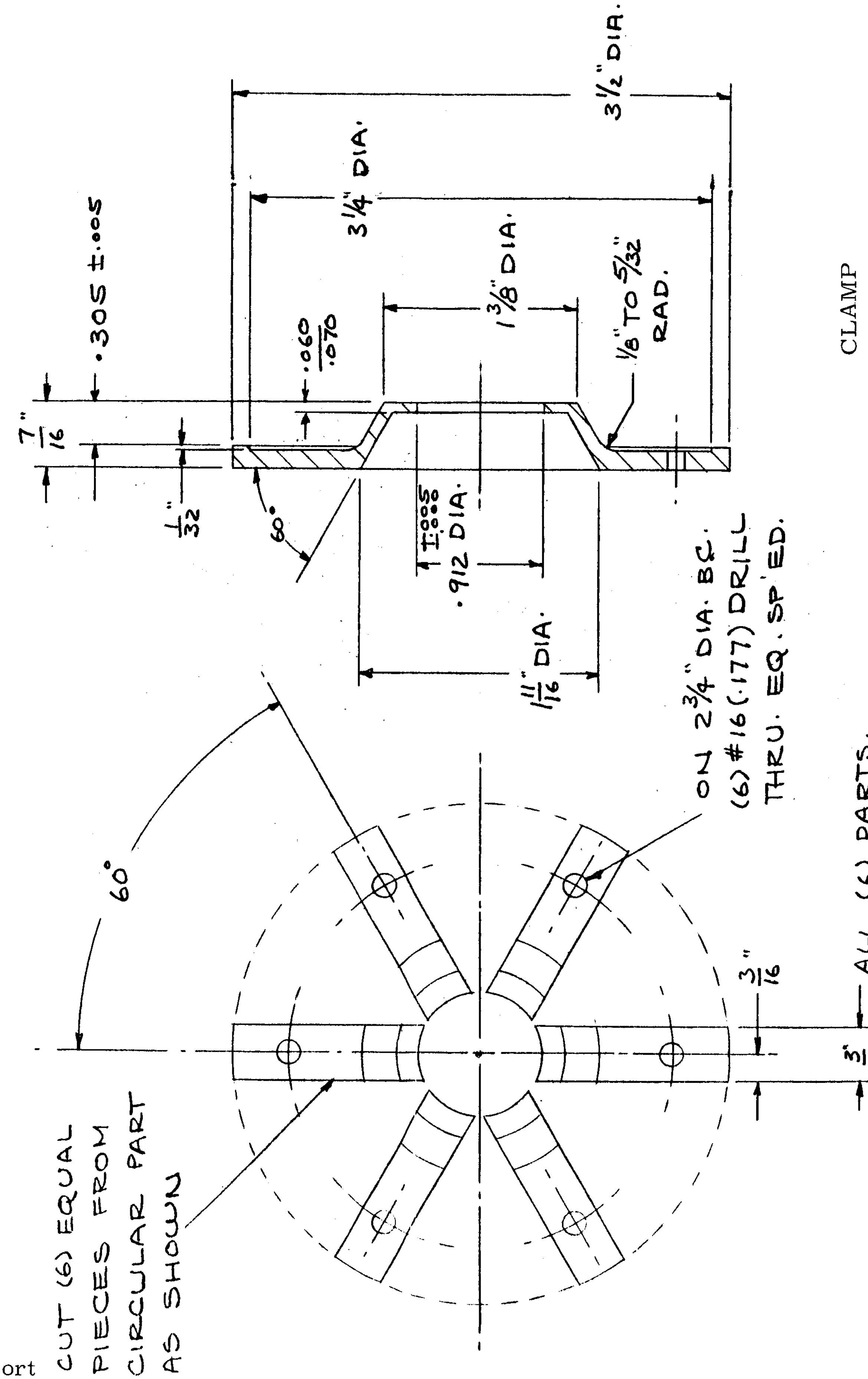
EXHAUST PIPE

14070



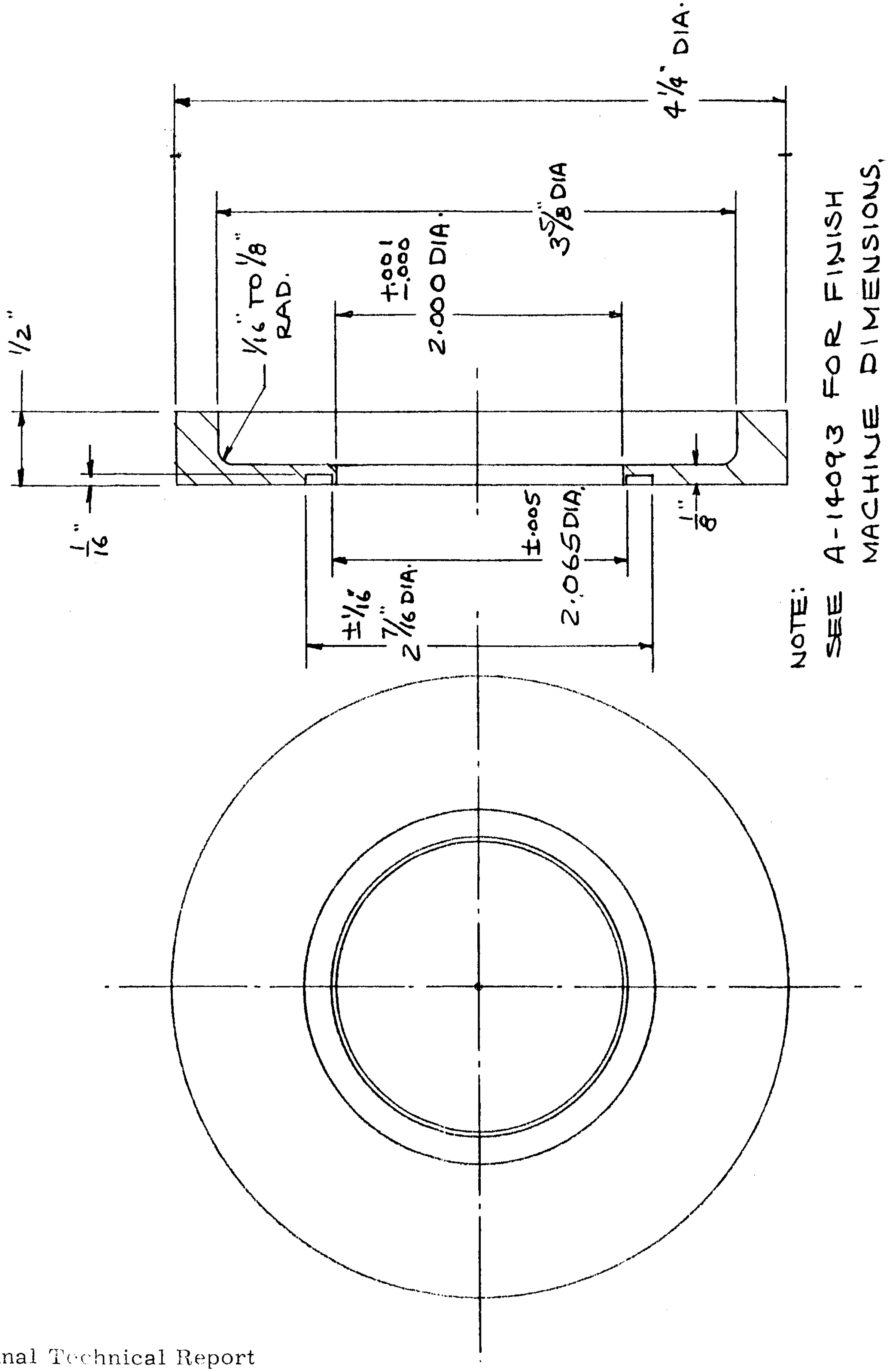
CONVERTER CONNECTOR

14071


3 1/2" DIA.
3 1/4" DIA.
.305 ±.005
.060
.070
1 3/8" DIA.
1/8" TO 5/32" RAD.
7/16"
1/32"
60°
±.005
.000
.912 DIA.
1 11/16" DIA.
ON 2 3/4" DIA. BC.
(6) #16 (.177) DRILL
THRU. EQ. SP'ED.
ALL (6) PARTS.
3/16"
3/8"
60°
CUT (6) EQUAL
PIECES FROM
CIRCULAR PART
AS SHOWN

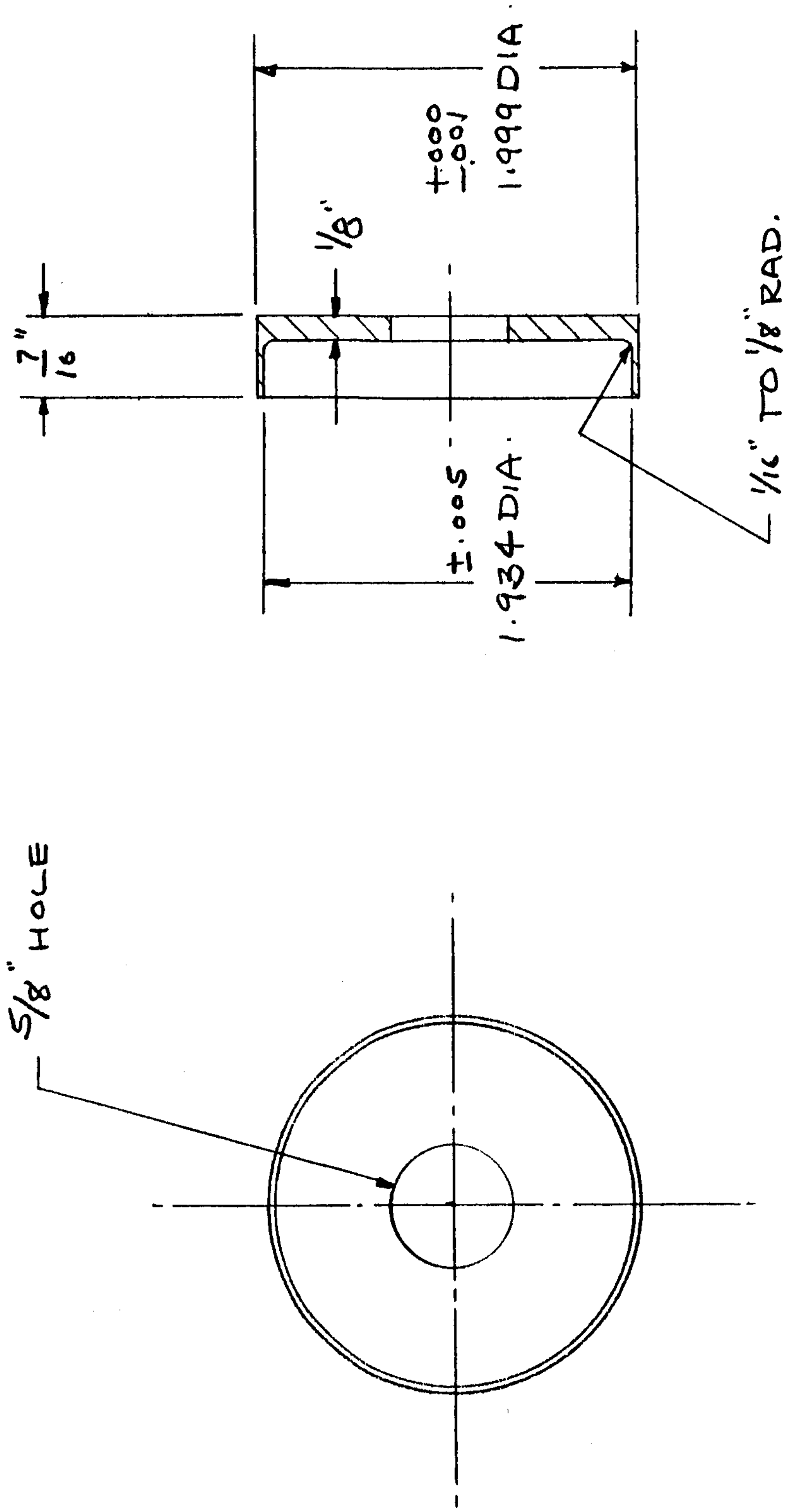
CLAMP

14072



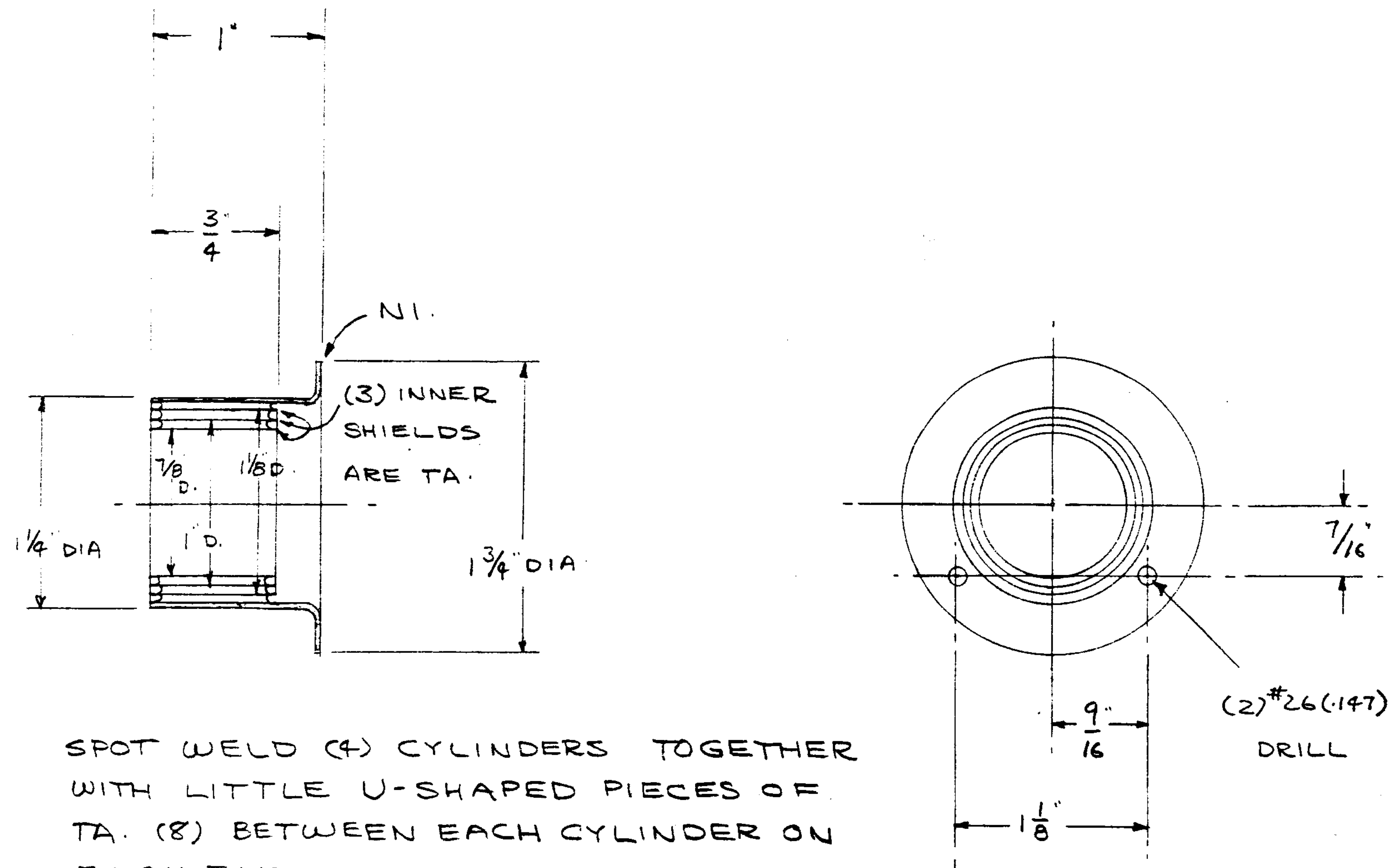
SEAT MOUNT

14073



NOTE:
SEE A-14093 FOR FINISH
MACHINE DIMENSIONS.

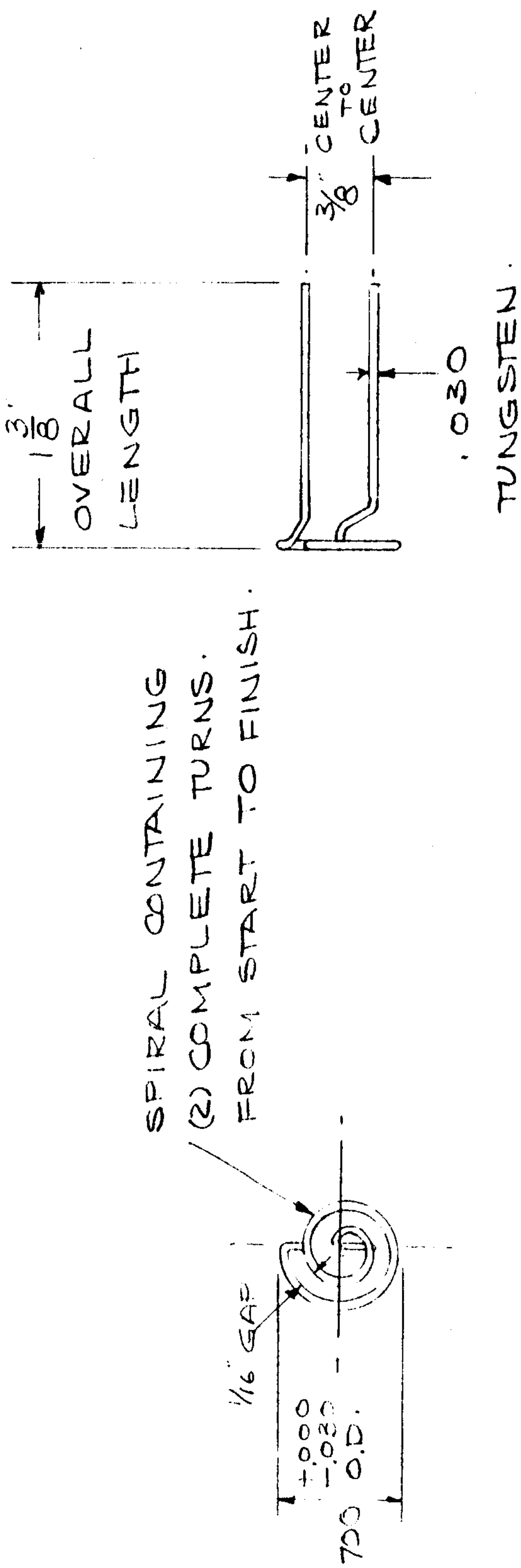
SEAT
14074



SPOT WELD (4) CYLINDERS TOGETHER WITH LITTLE U-SHAPED PIECES OF TA. (8) BETWEEN EACH CYLINDER ON EACH END.

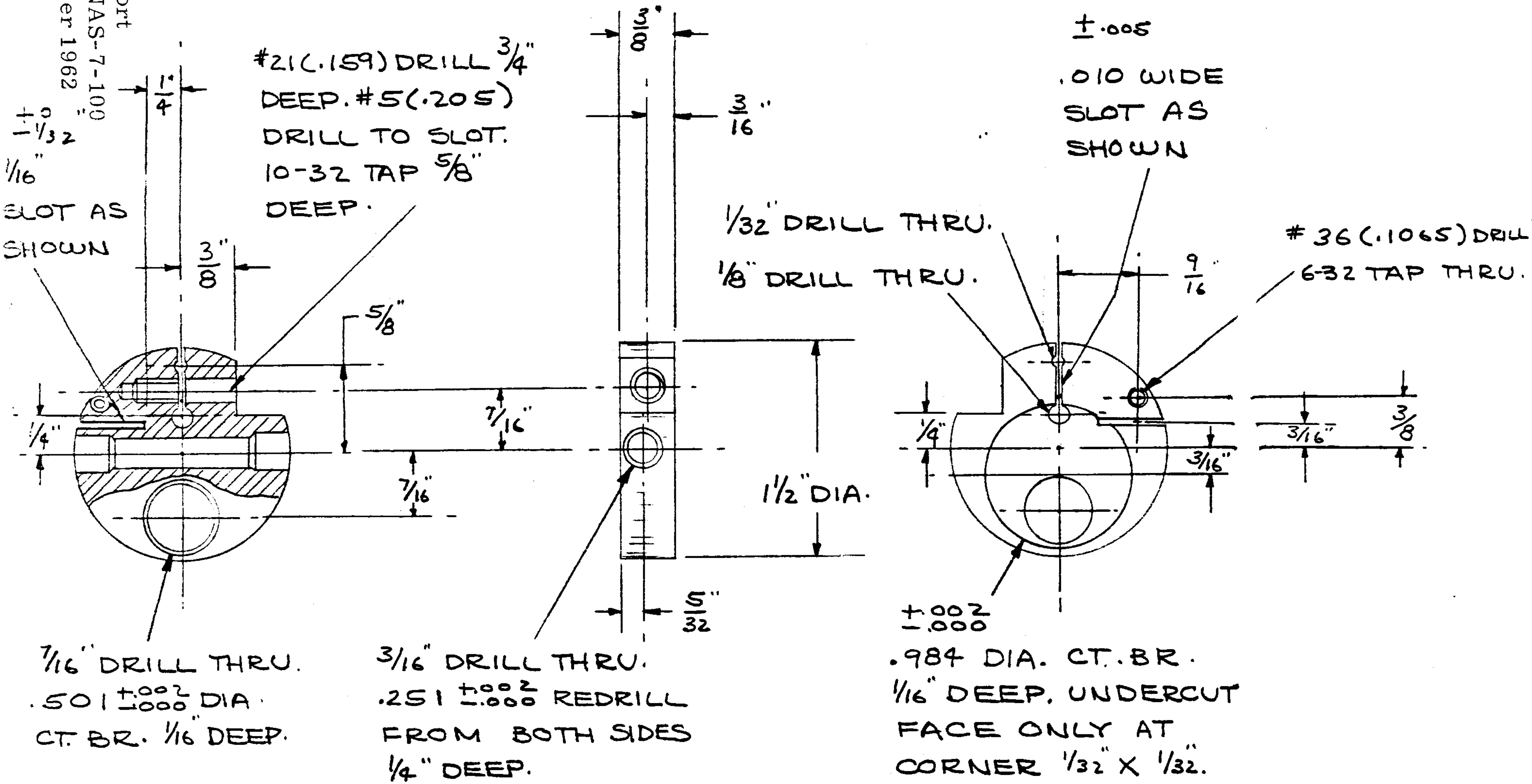
HEAT SHIELD ASSEMBLY

14077



ELECTRON BOMBARDMENT HEATER

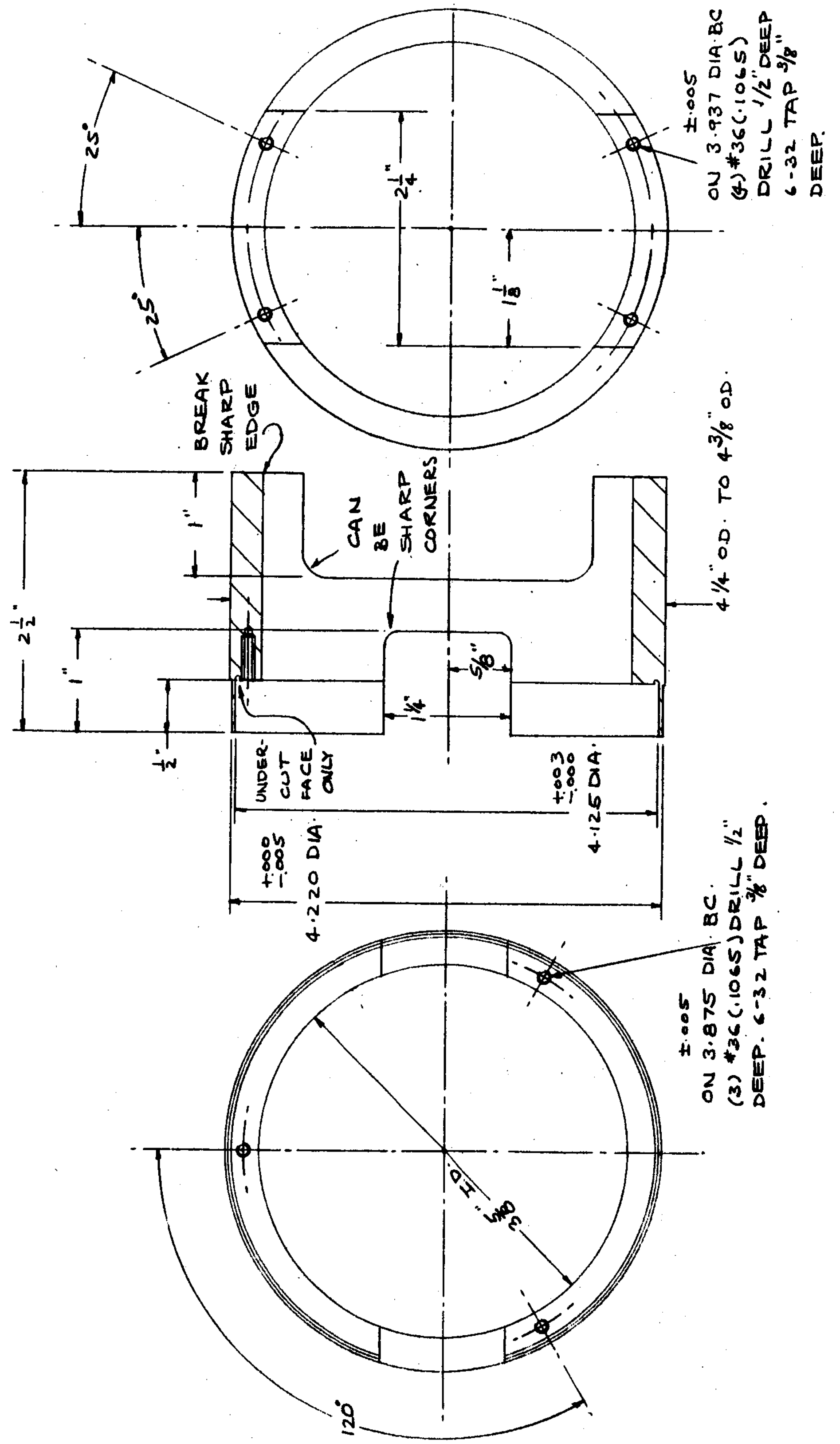
14078



HEATER TERMINAL

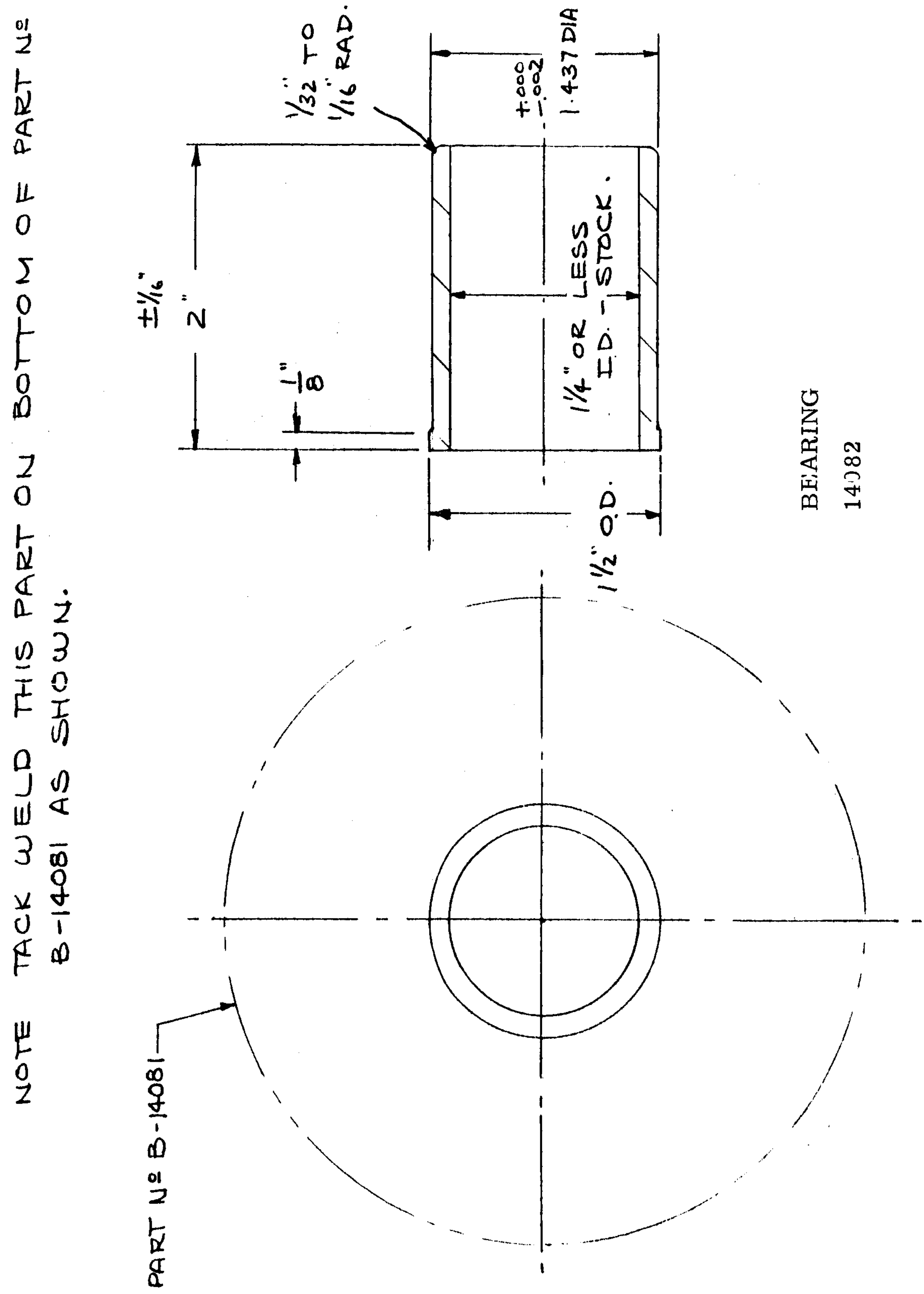
14079

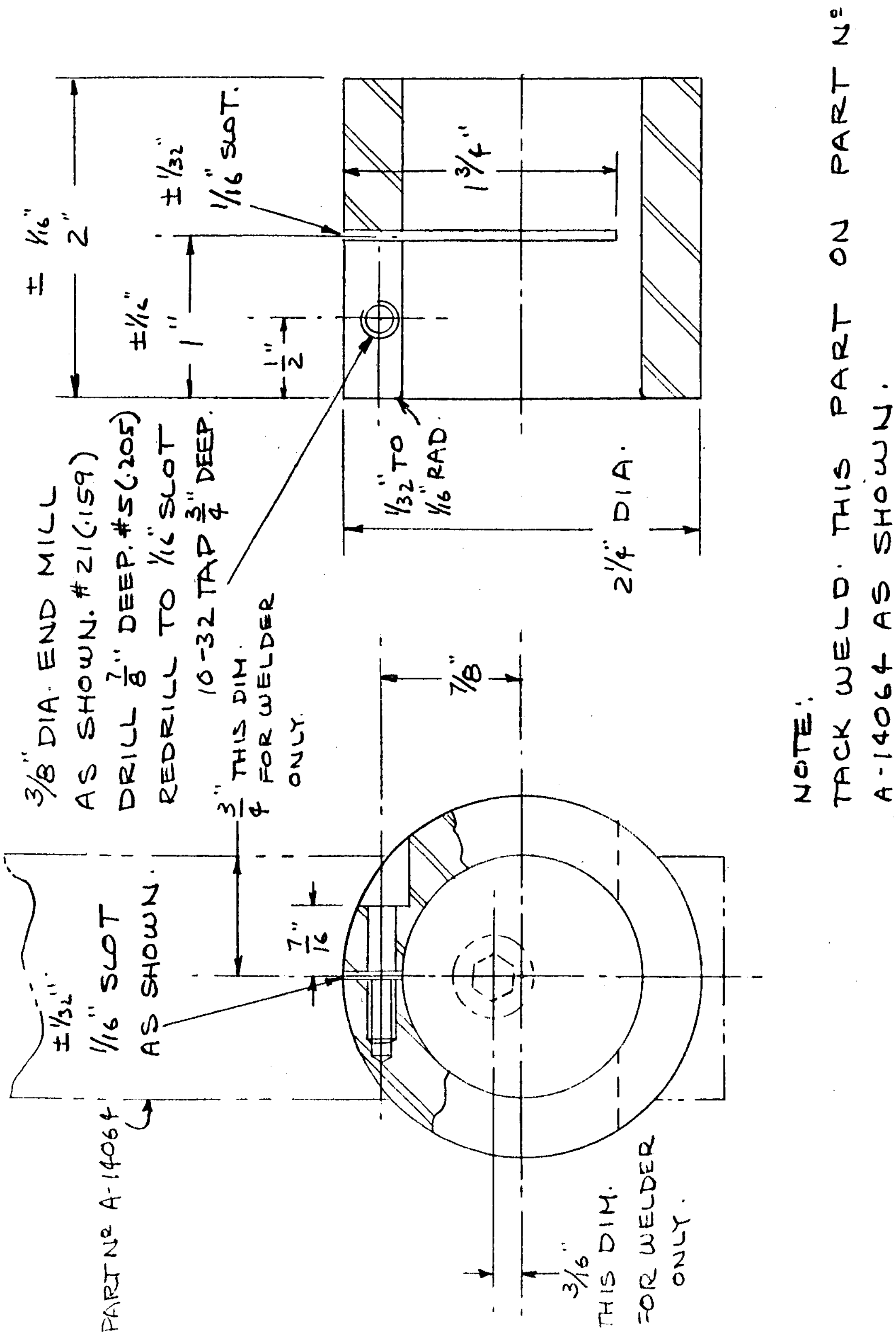
37000-29



CYLINDER

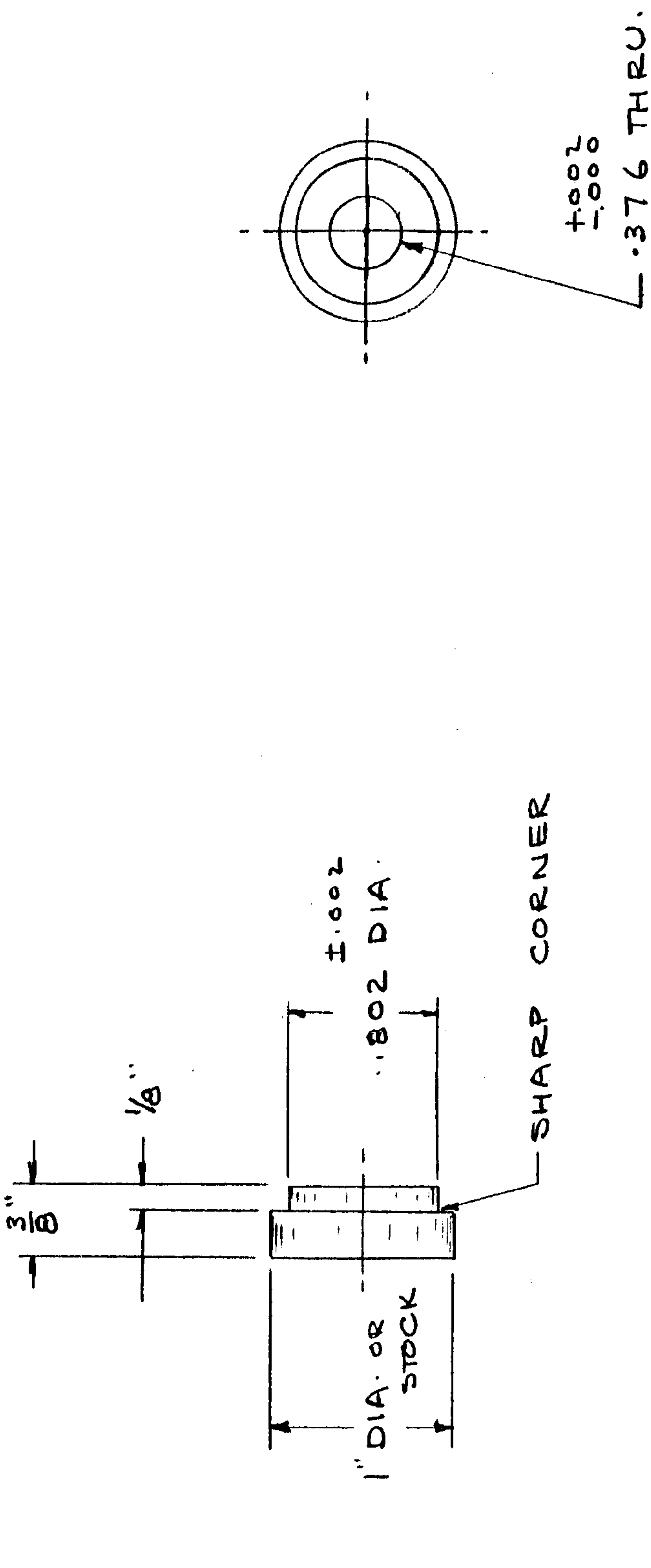
14080


NOTE TACK WELD THIS PART ON BOTTOM OF PART Nº
B-14081 AS SHOWN.
PART Nº B-14081
±1/16"
2"
1/8"
1/32" TO 1/16" RAD.
+.000 -.002
1.437 DIA
1 1/4" OR LESS I.D. - STOCK.
1 1/2" O.D.
BEARING
14082



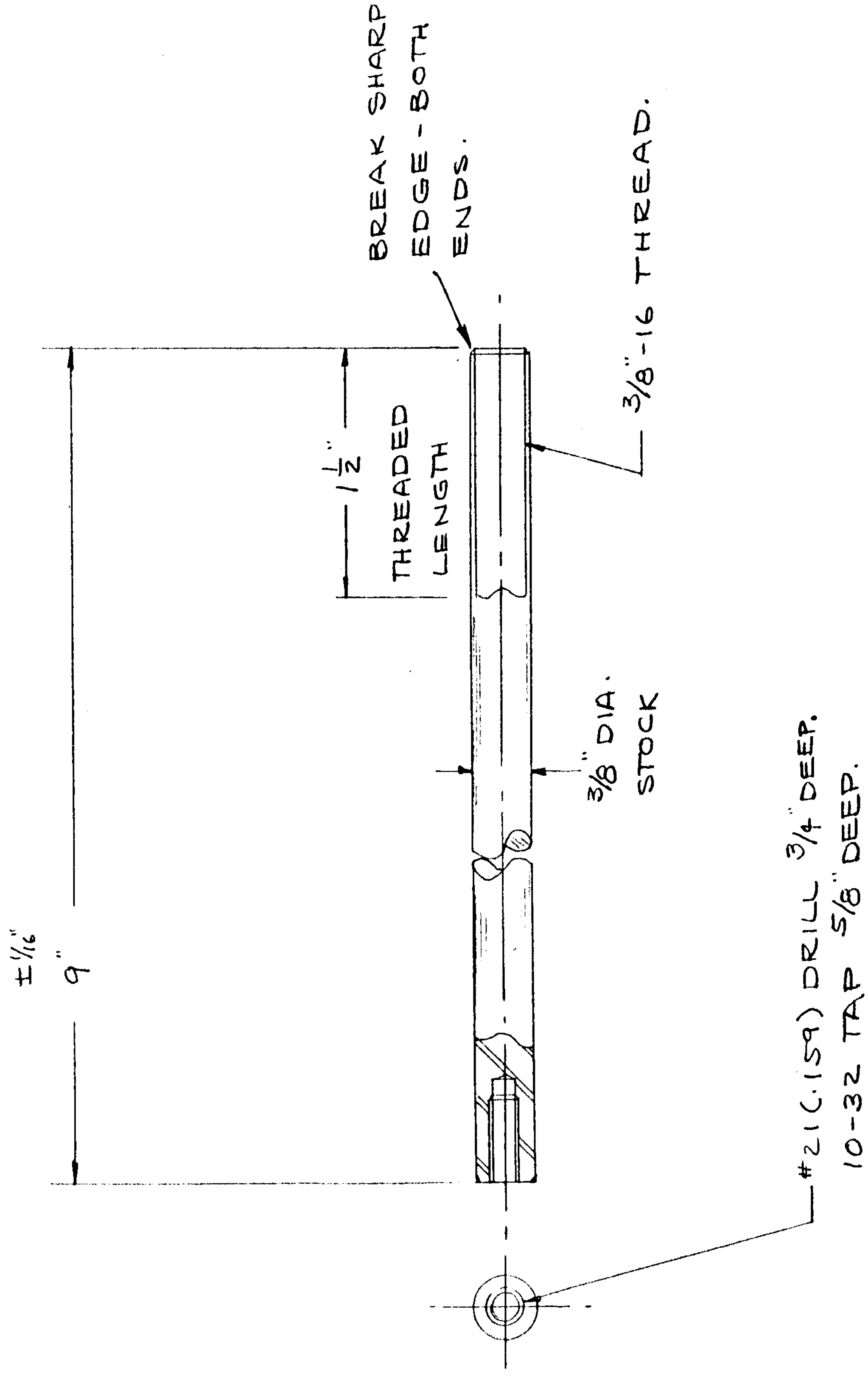
BEARING MOUNT

14083



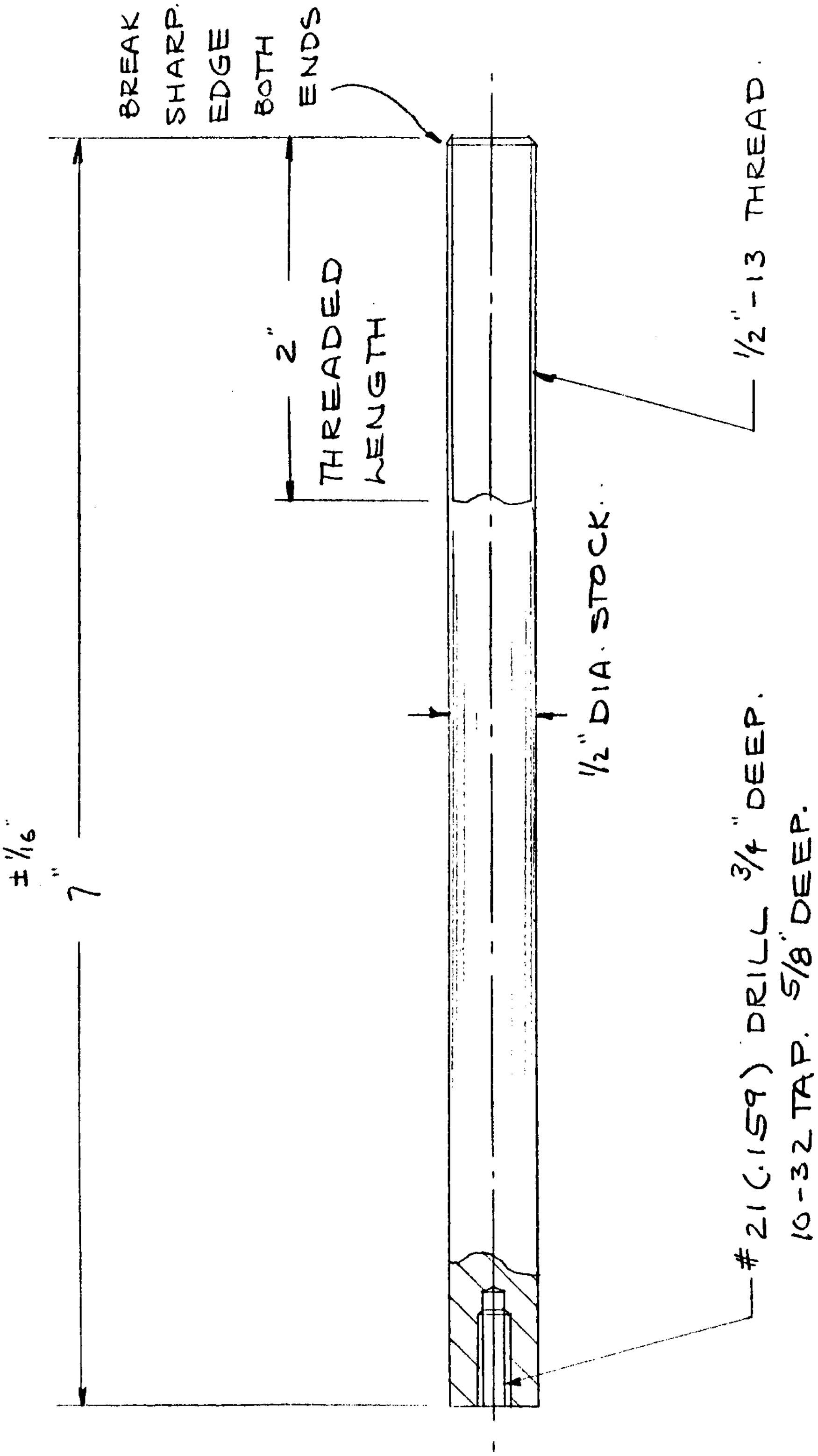
HEATER WATER TERMINAL

14084



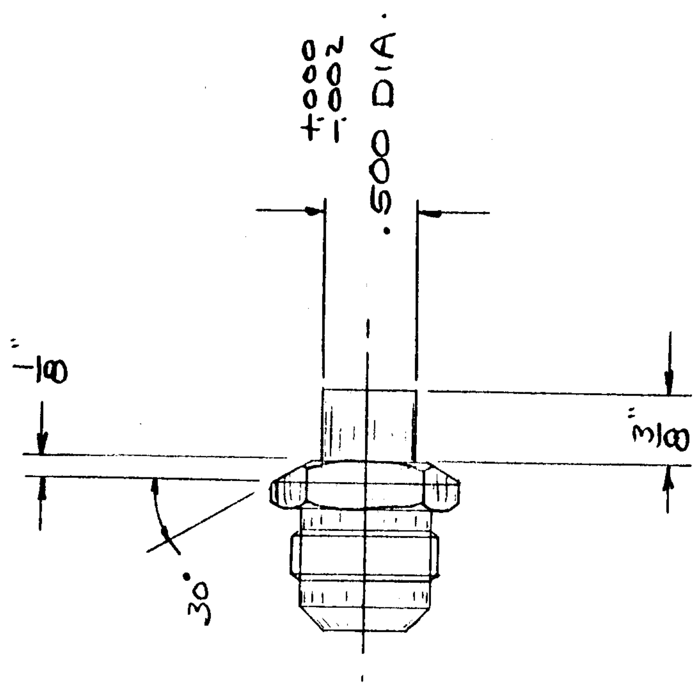
COLLECTOR TERMINAL

14085



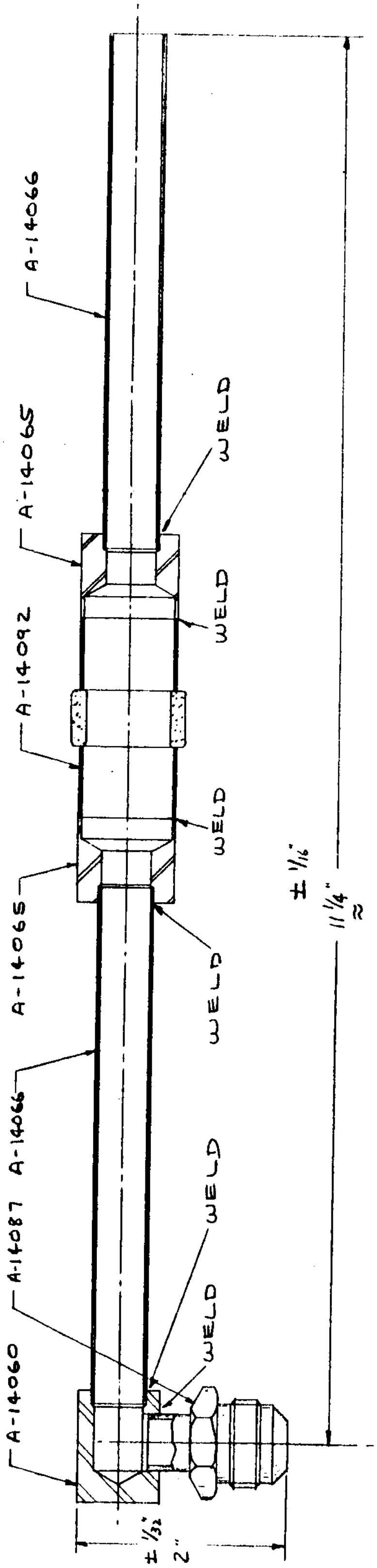
EMITTER TERMINAL

14086



EXHAUST LINE FITTING

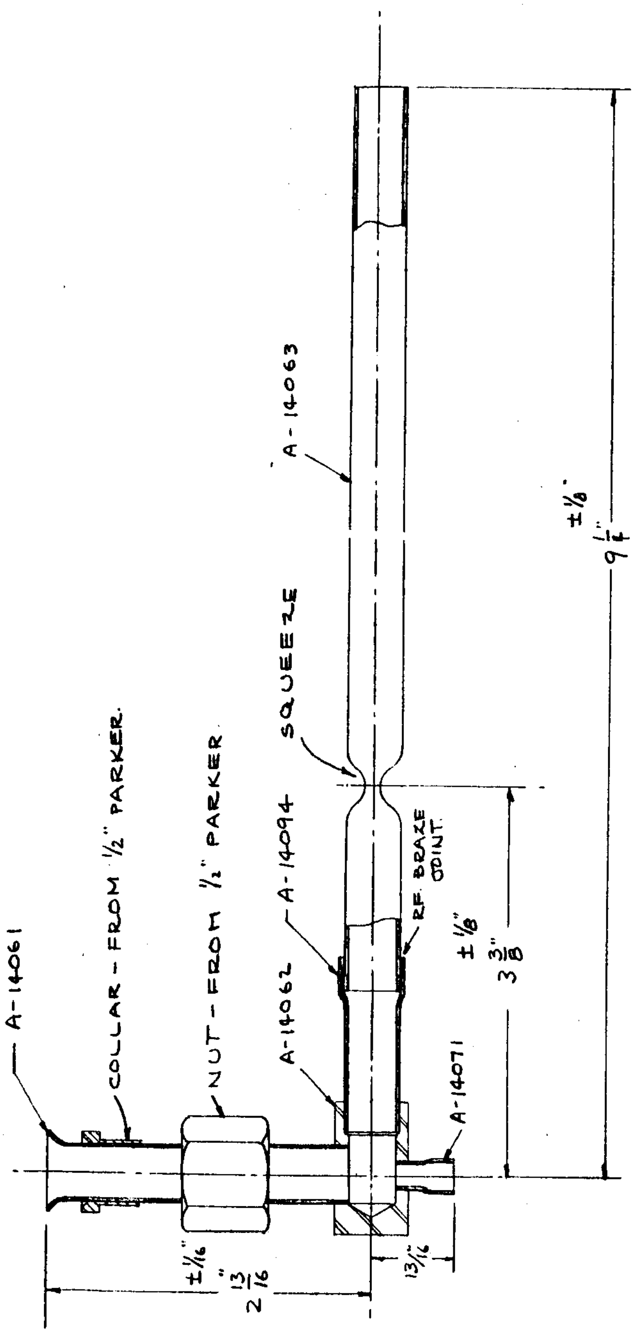
14087



NOTE: ALL JOINTS MUST BE VACUUM TIGHT.
ALL WELDS ARE FUSION ARC WELDS.

MANIFOLD ASSEMBLY

14088

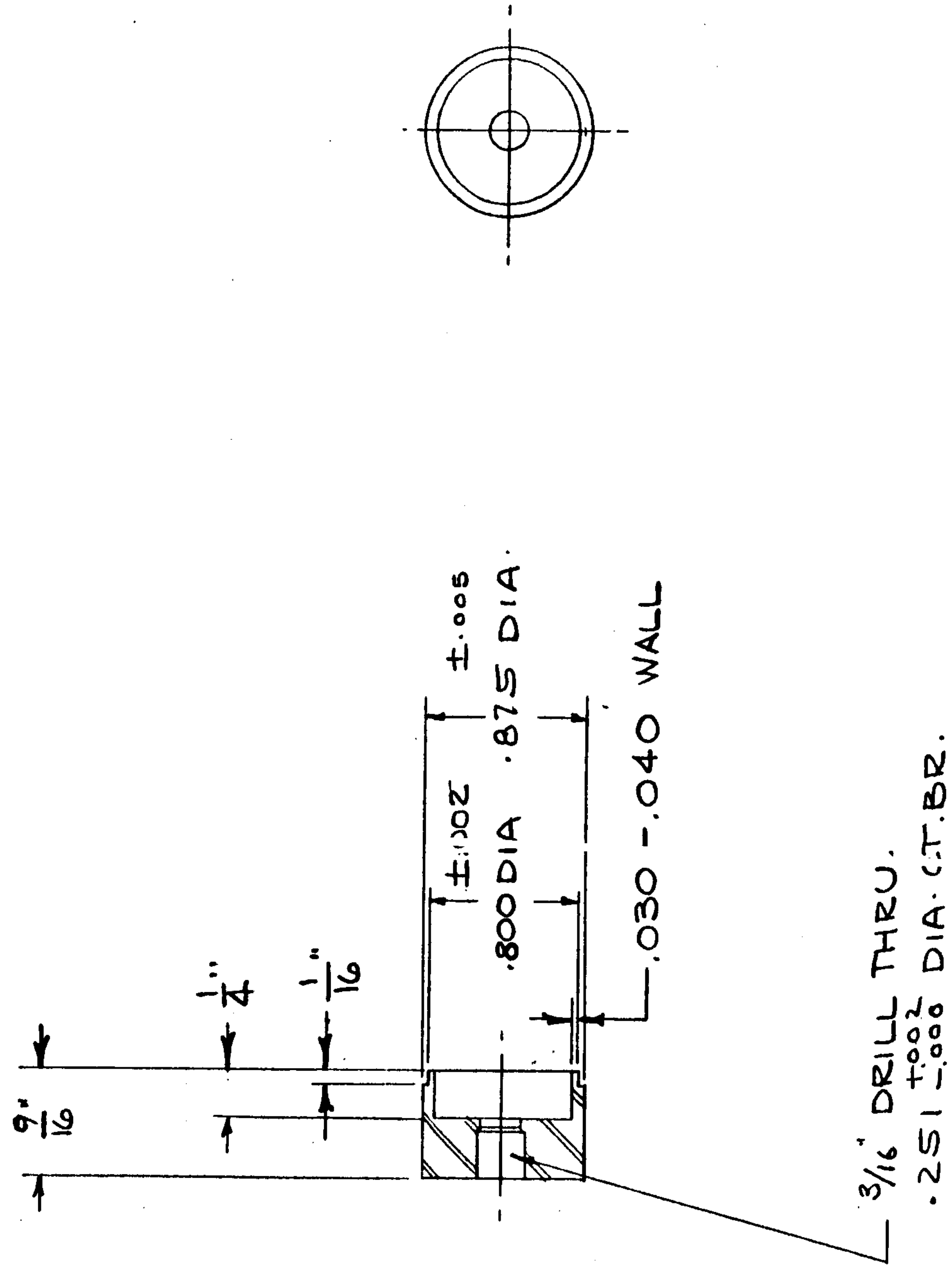


NOTES:

1. CLEAN PARTS THOROUGHLY.
2. B.T. BRAZE 830°C & LEAK CHECK.
3. ASSEMBLE COLLAR & NUT, FLARE AS SHOWN
4. RF BRAZE PART No A-14063 TO ASSY, & LEAK CHECK.
5. SQUEEZE PART No A-14063 TO RETAIN CESIUM CAPSULE.

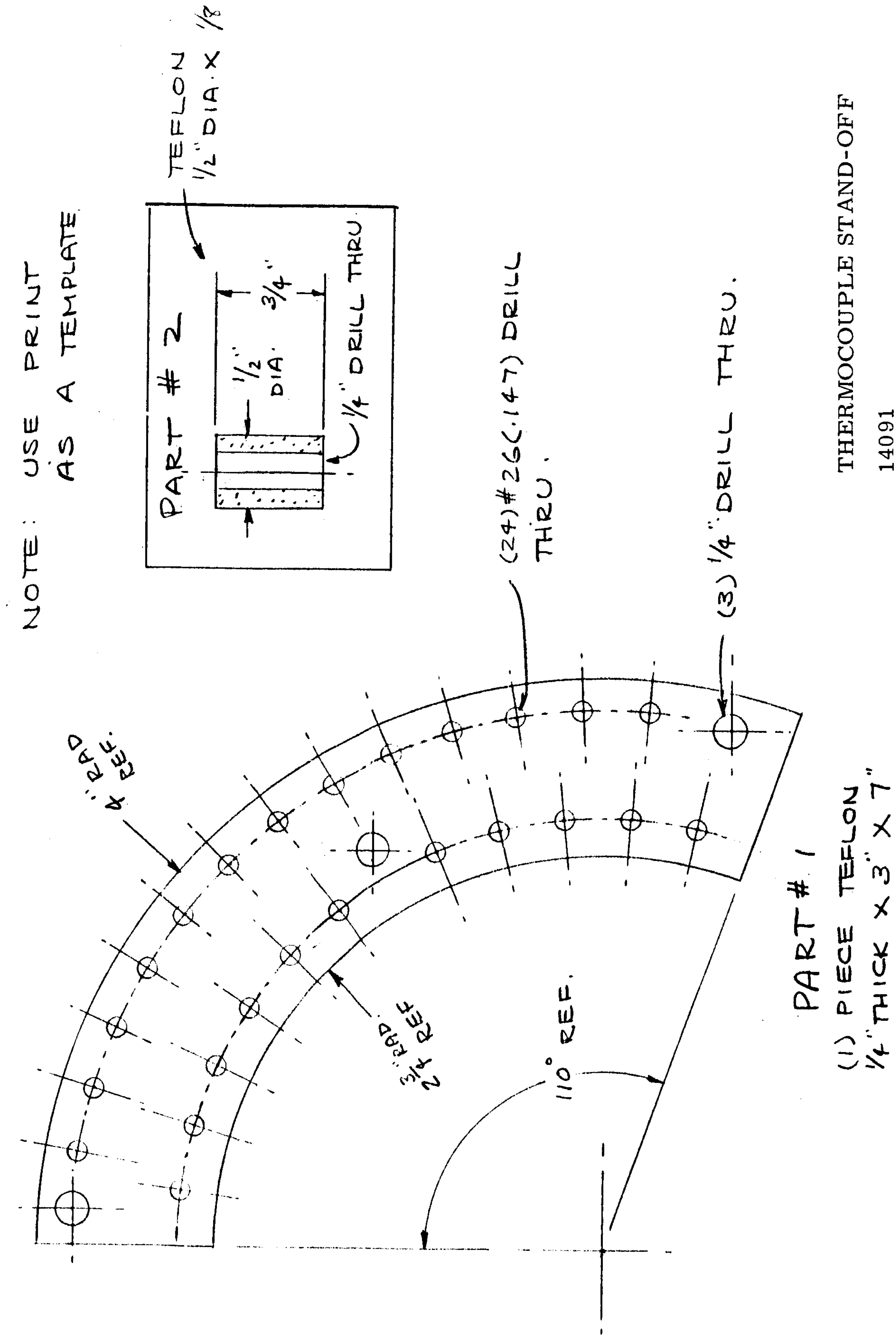
EXHAUST ASSEMBLY

14089



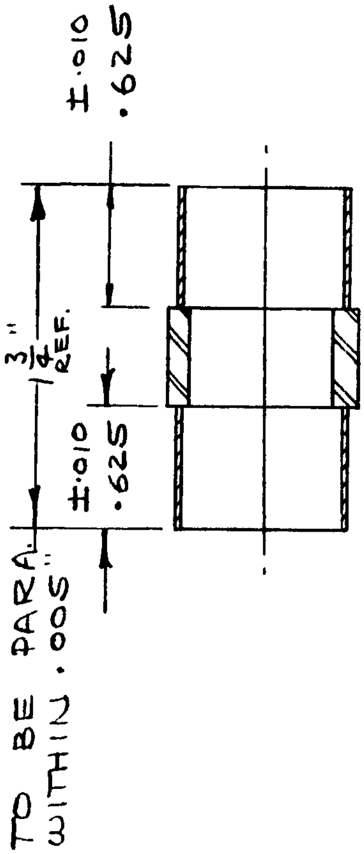
INSULATOR ADAPTOR

14090



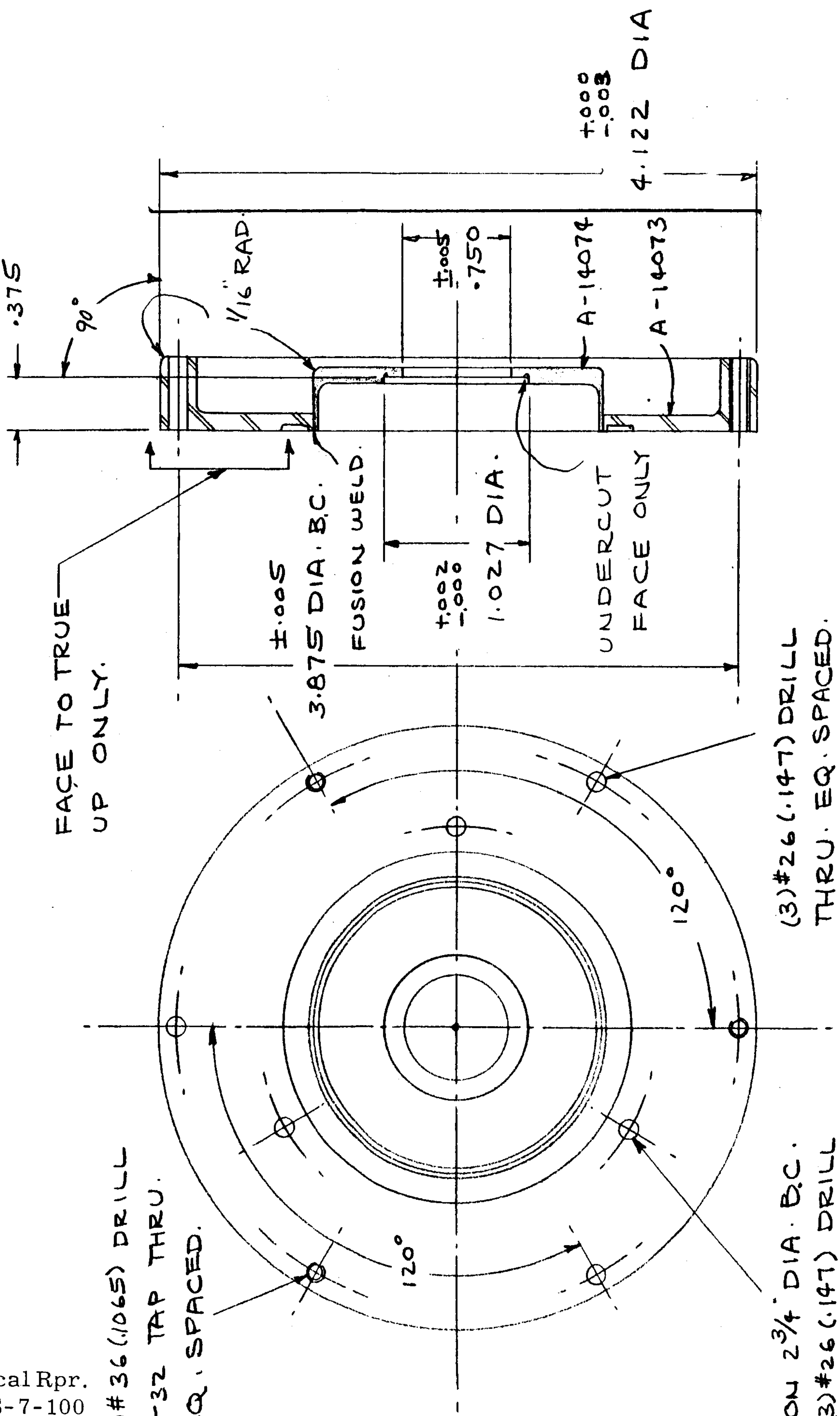
THERMOCOUPLE STAND-OFF

14091



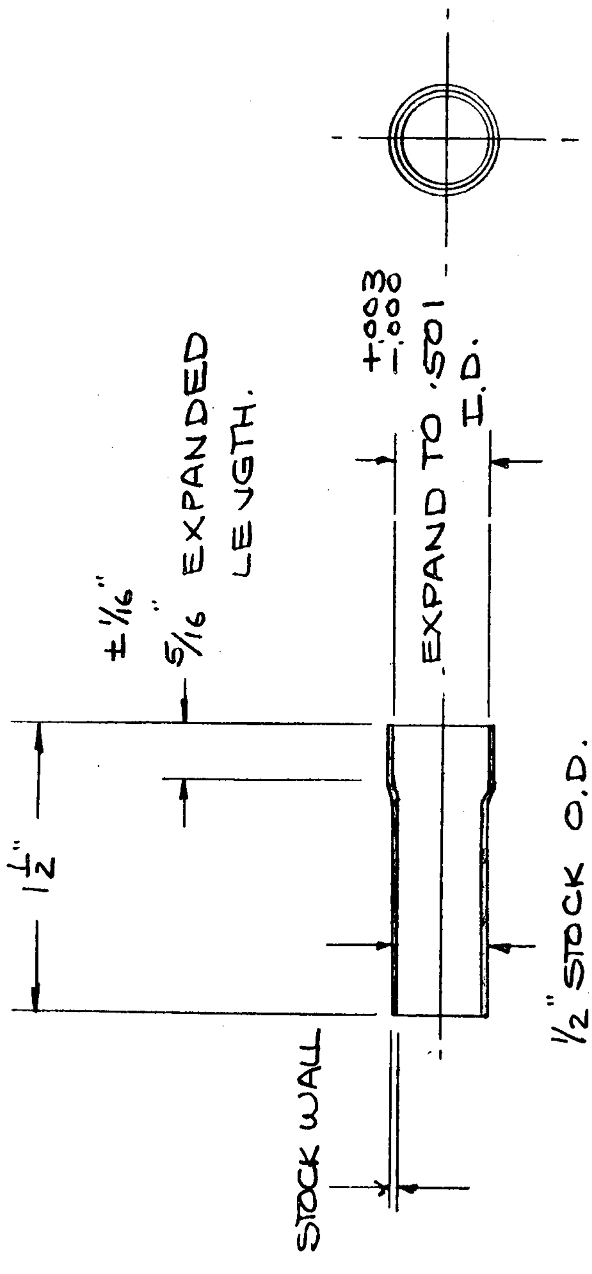
TERMINAL ASSEMBLY

14092



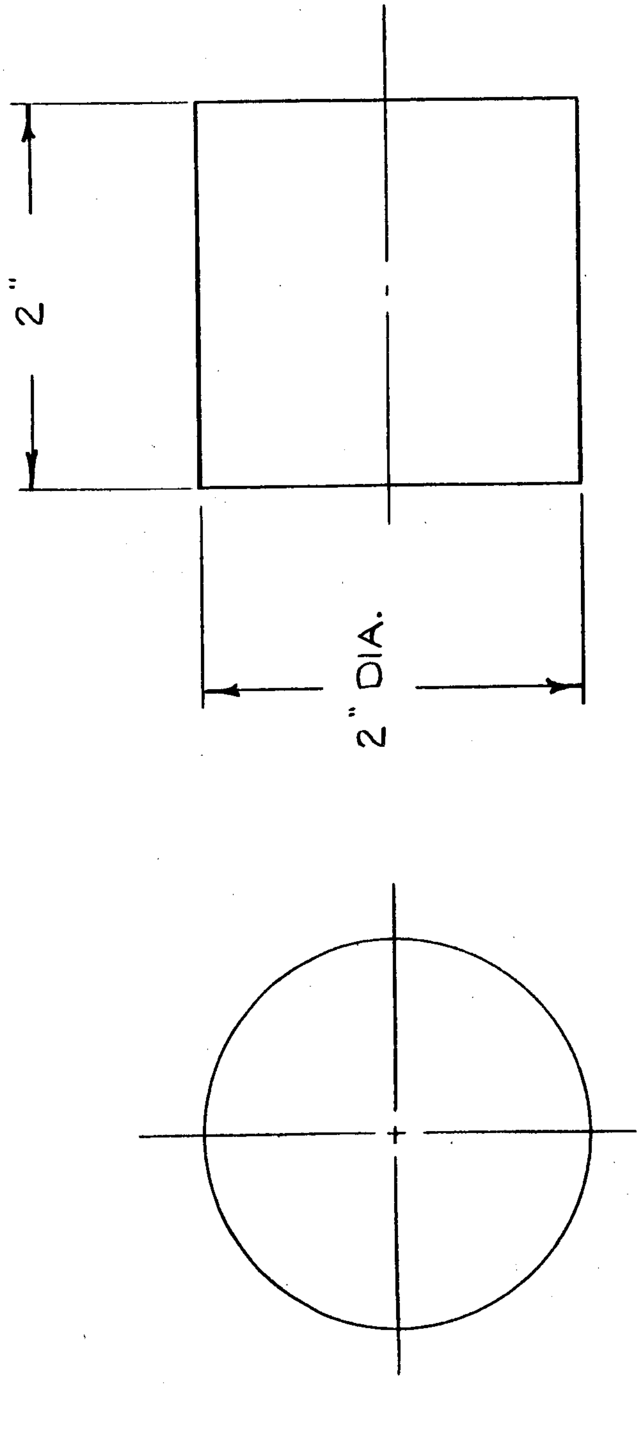
FINISHED MACHINE DRAWING

14093



EXHAUST LINE EXPANSION

14094

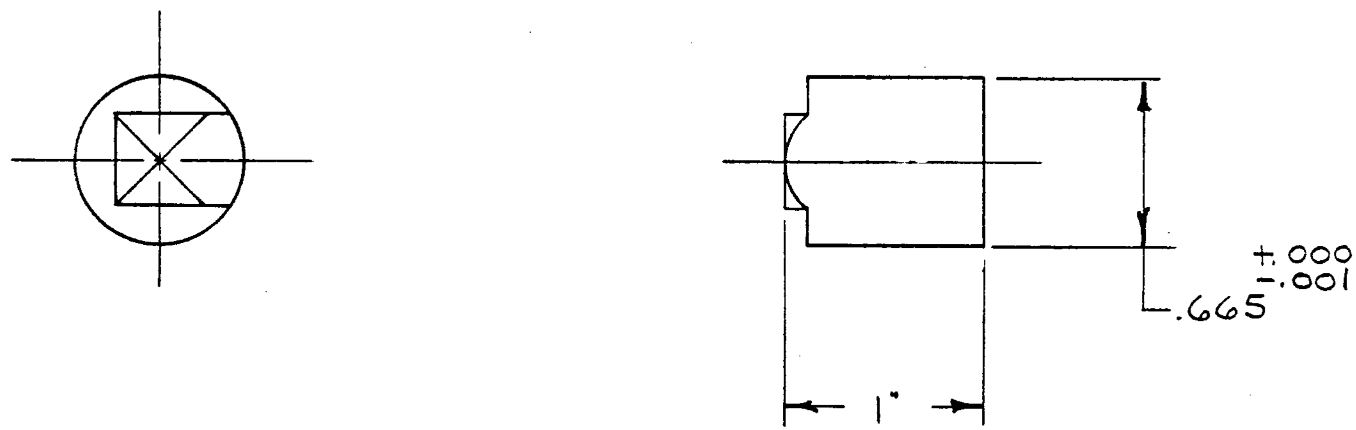


NOTES:
1. ENDS OF PART TO BE PARALLEL WITHIN .001.

PUNCH BLANK
14101

NOTES:

1. O.D. TO BE GROUND.
2. HARDEN TO R.C. 66-68.

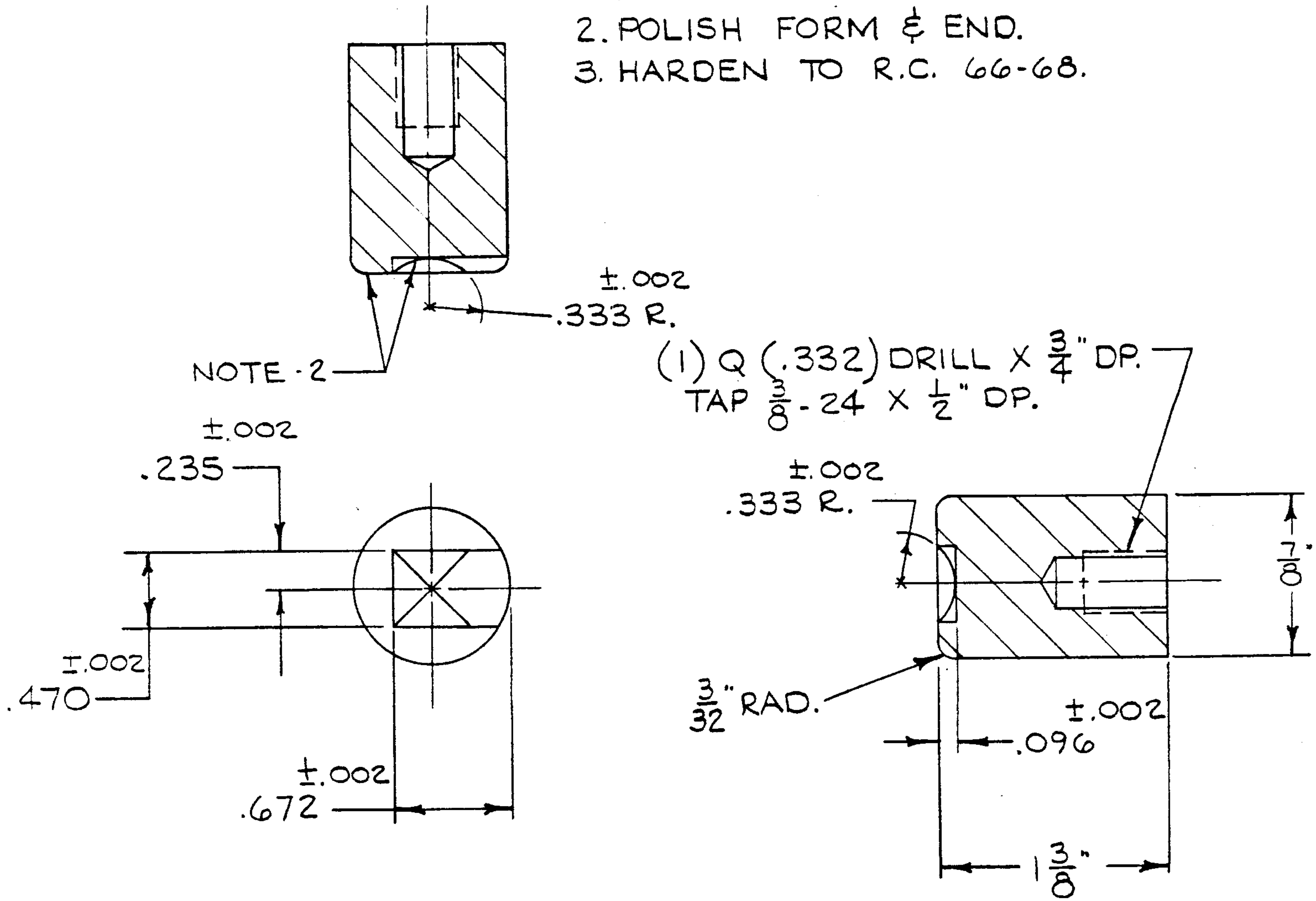


PUNCH

14102

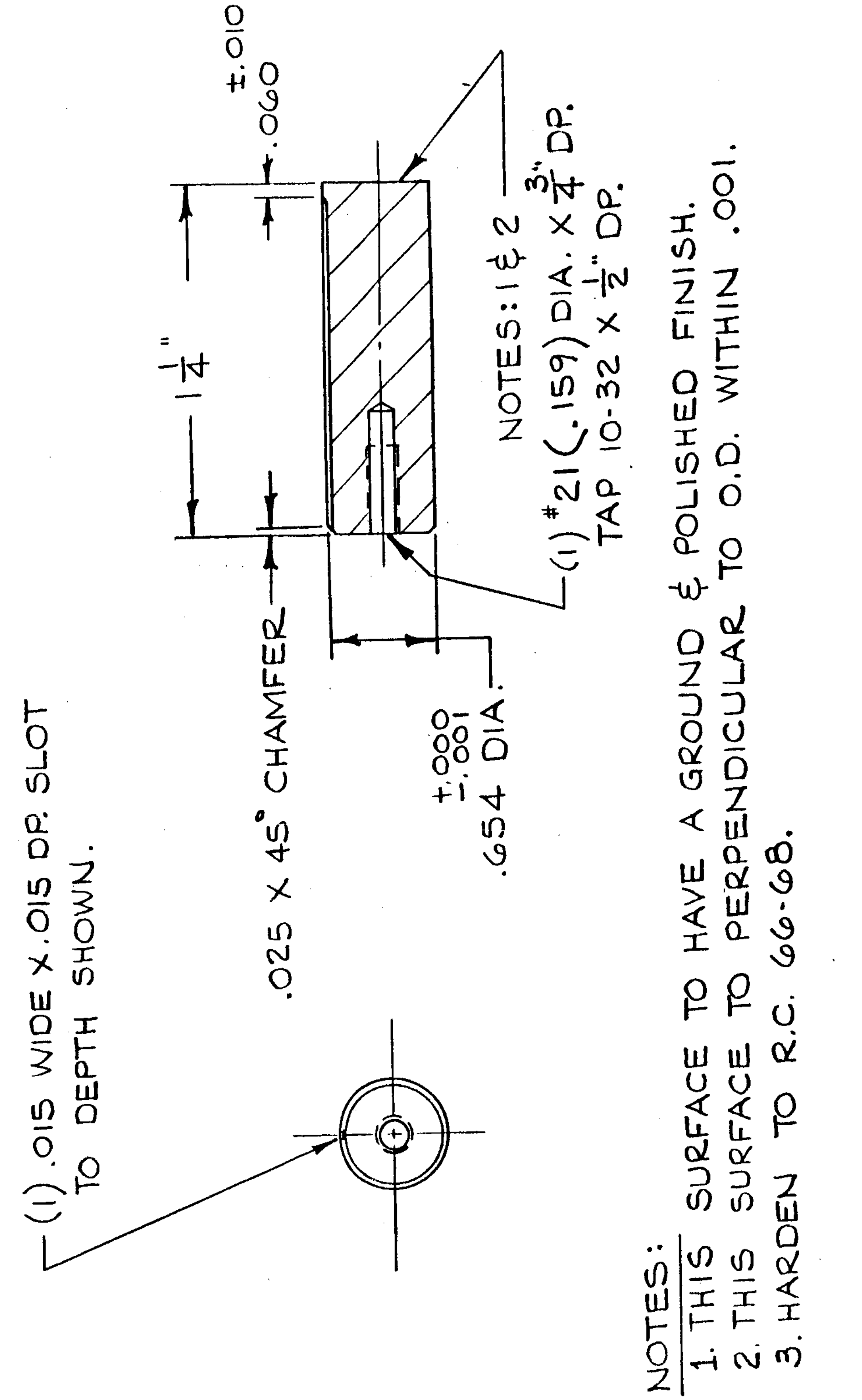
NOTES:

1. ENDS OF PART TO BE PARALLEL WITHIN .001.
2. POLISH FORM & END.
3. HARDEN TO R.C. 66-68.



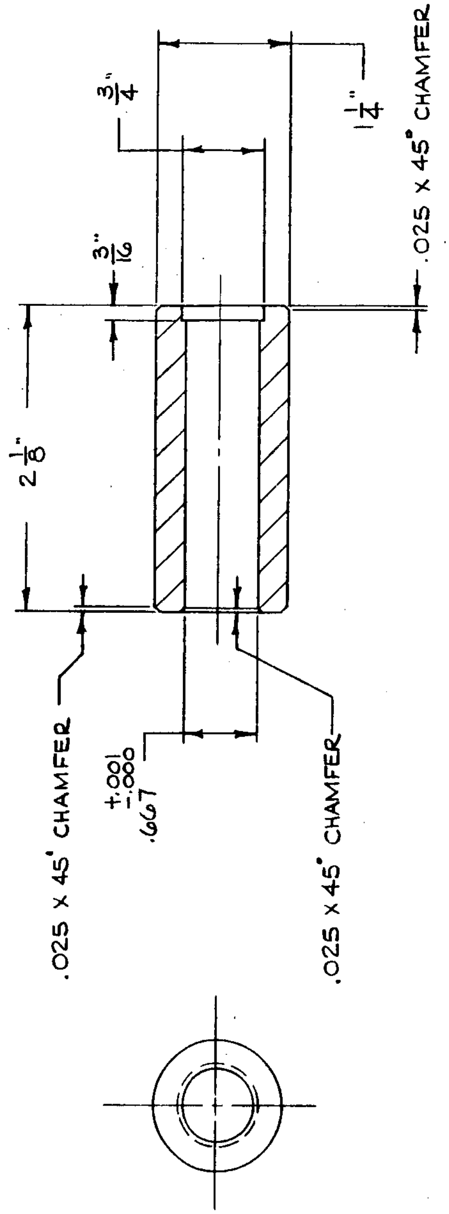
PUNCH HOB

14103



PUNCH GUIDE

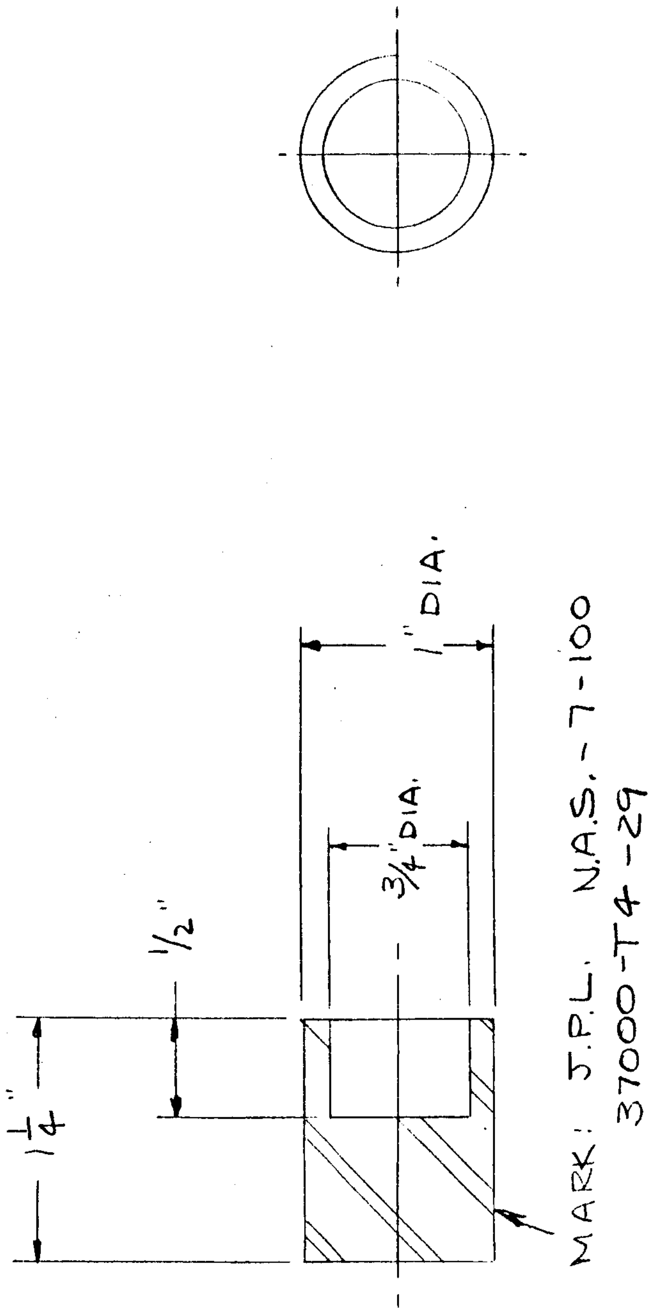
14104



NOTES:
1. I.D. TO HONE FINISH.
2. HARDEN TO R.C. 66-68.

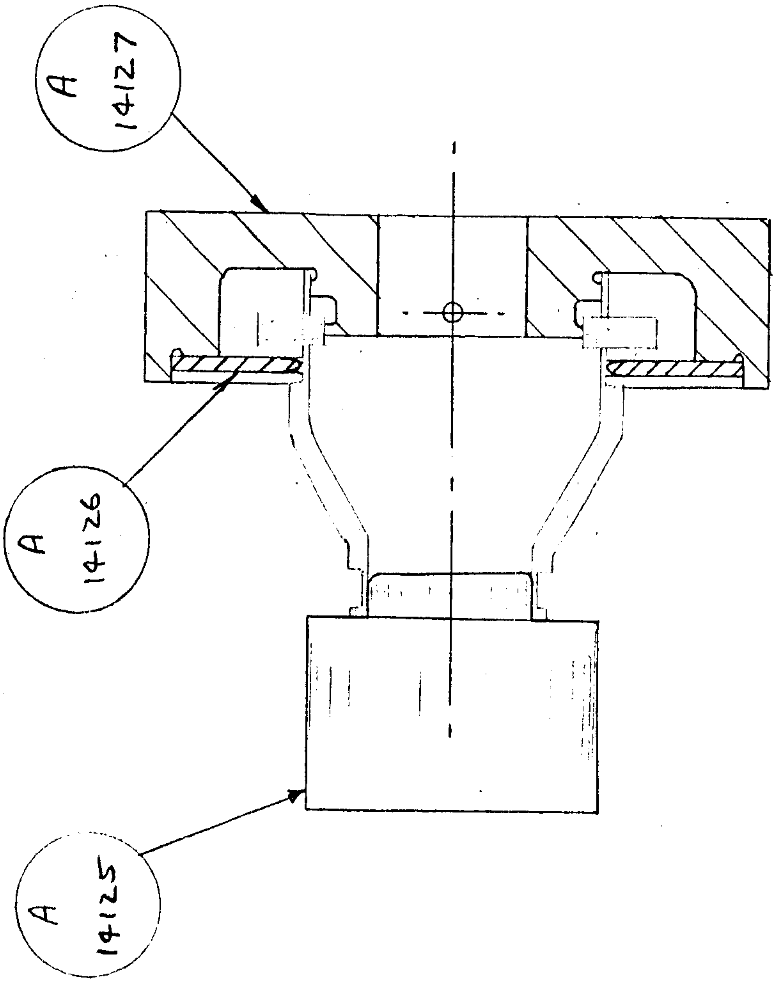
PUNCH BARREL

14105

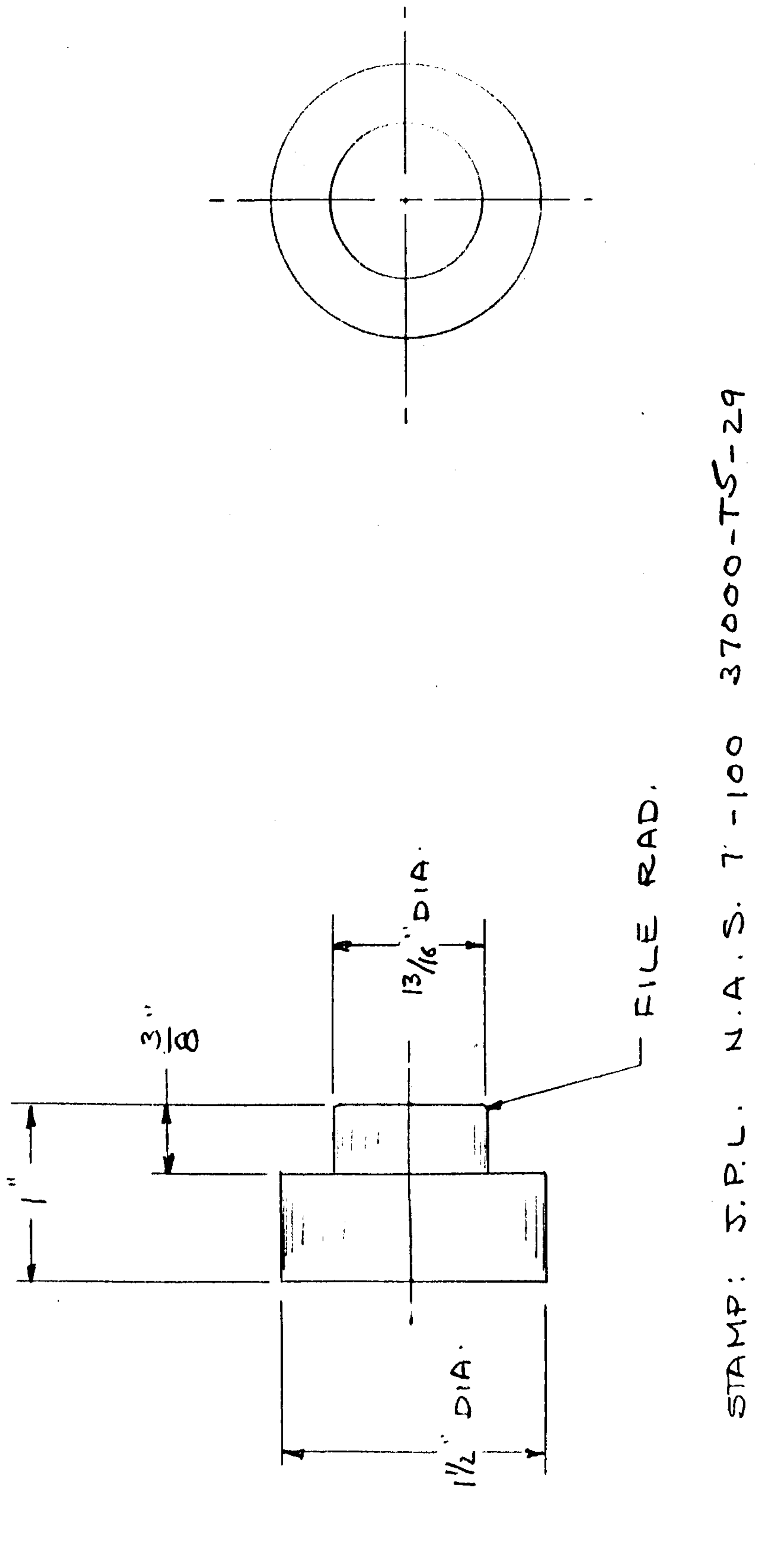


WEIGHT

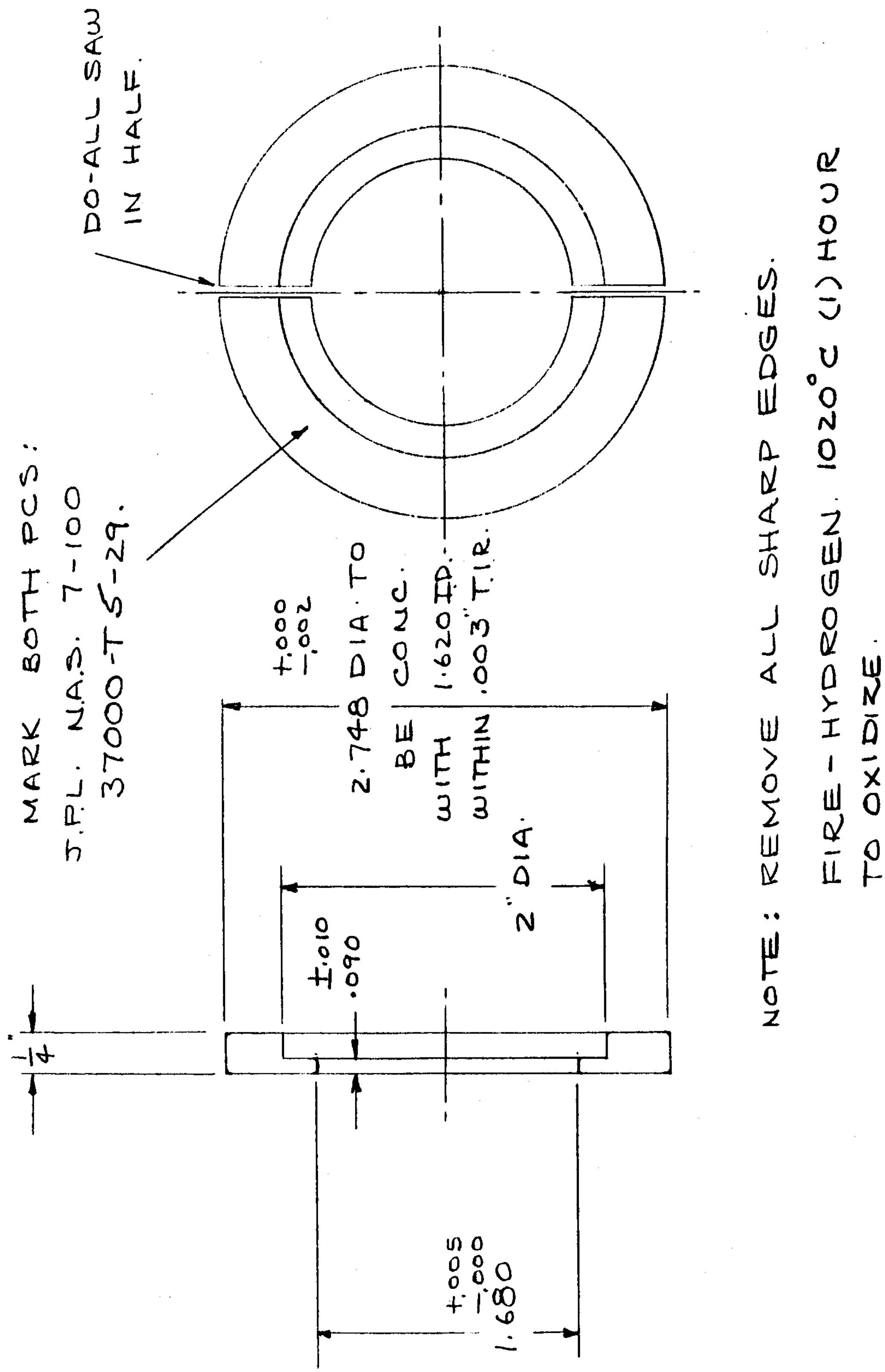
14123



BRAZING JIG
14124

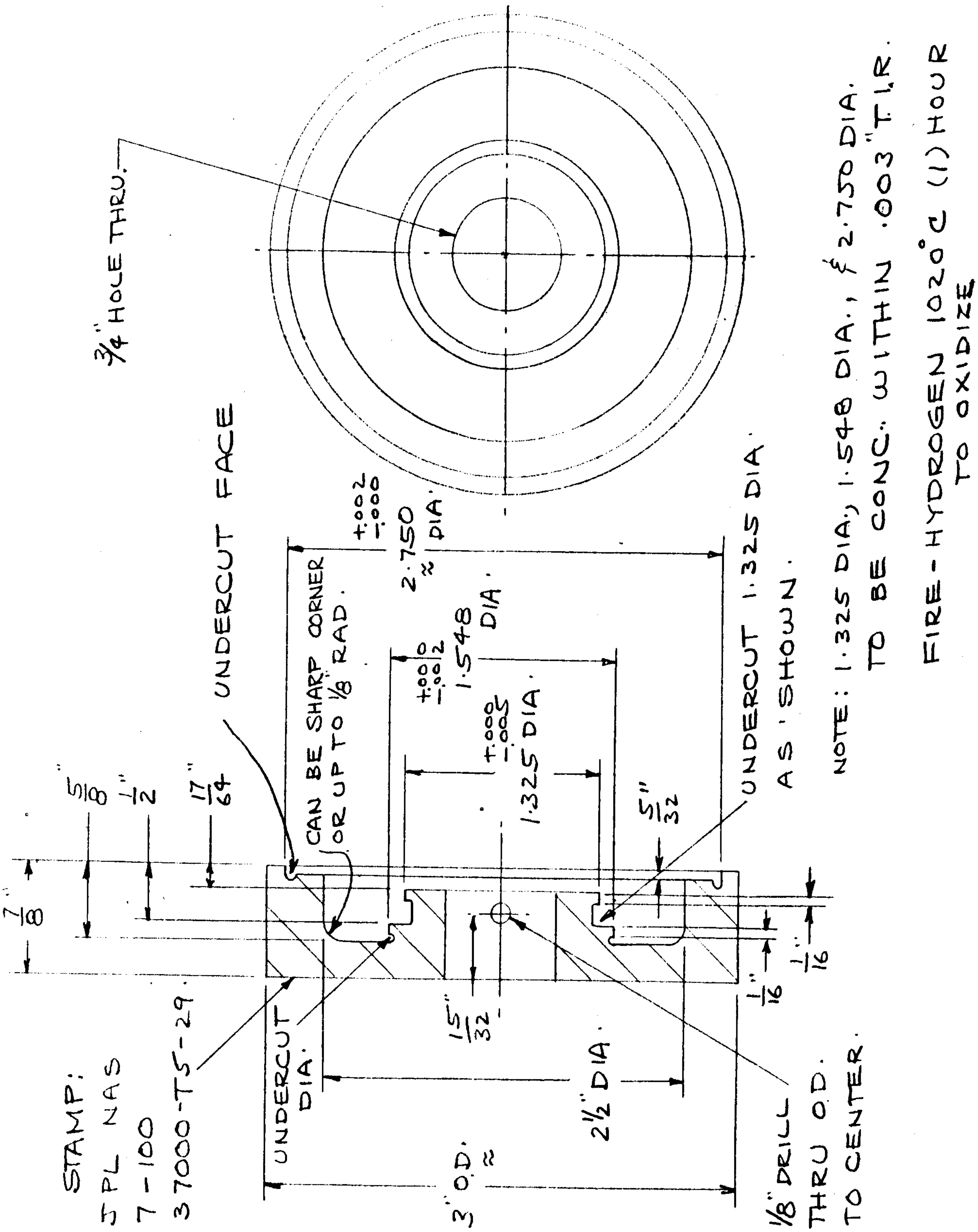


WEIGHT
14125

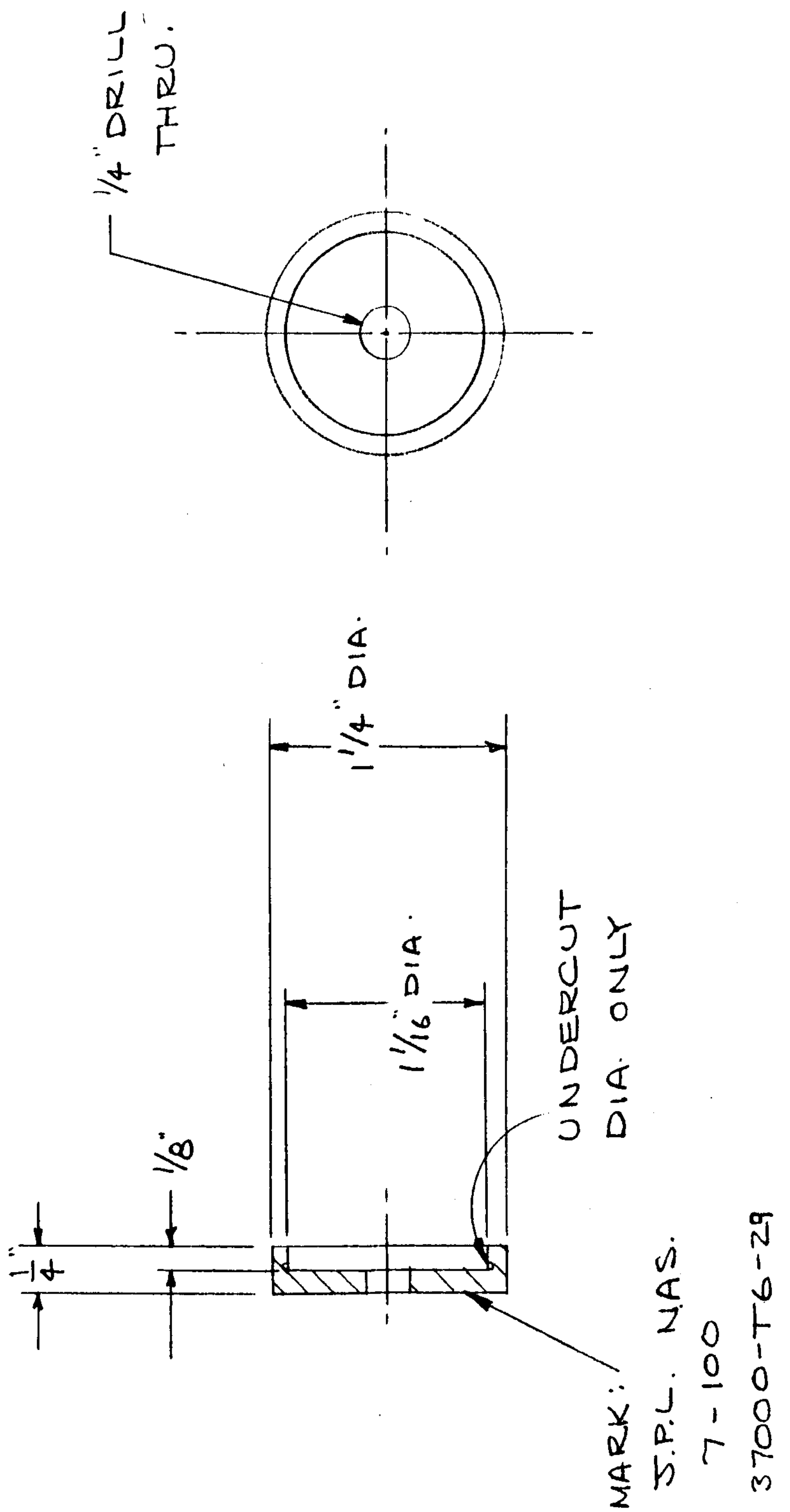


SPLIT RING

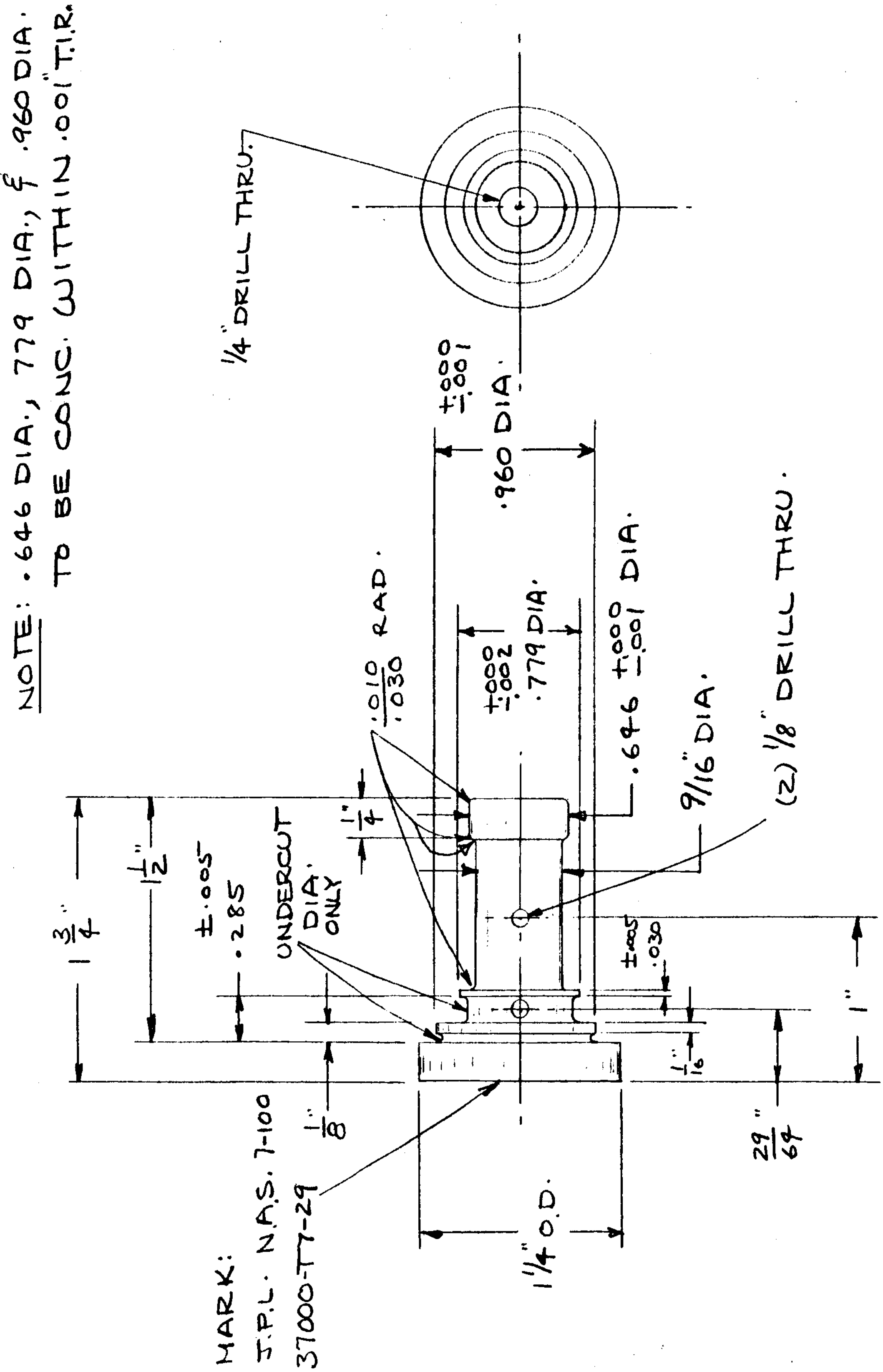
14126


3/4" HOLE THRU.
UNDERCUT FACE
CAN BE SHARP CORNER OR UP TO 1/8" RAD.
2.750 +.002 -.000 DIA.
1.548 +.000 -.002 DIA.
1.325 +.000 -.005 DIA.
UNDERCUT 1.325 DIA AS SHOWN.
NOTE: 1.325 DIA., 1.548 DIA., ℄ 2.750 DIA.
TO BE CONC. WITHIN .003" T.I.R.
FIRE-HYDROGEN 1020°C (1) HOUR
TO OXIDIZE
7/8
5/8
1/2"
17/64"
5/32"
1/16"
1/16"
15/32"
STAMP:
JPL NAS
7-100
37000-TS-29
UNDERCUT DIA.
2 1/2" DIA.
3" O.D. ≈
1/8" DRILL
THRU O.D.
TO CENTER.

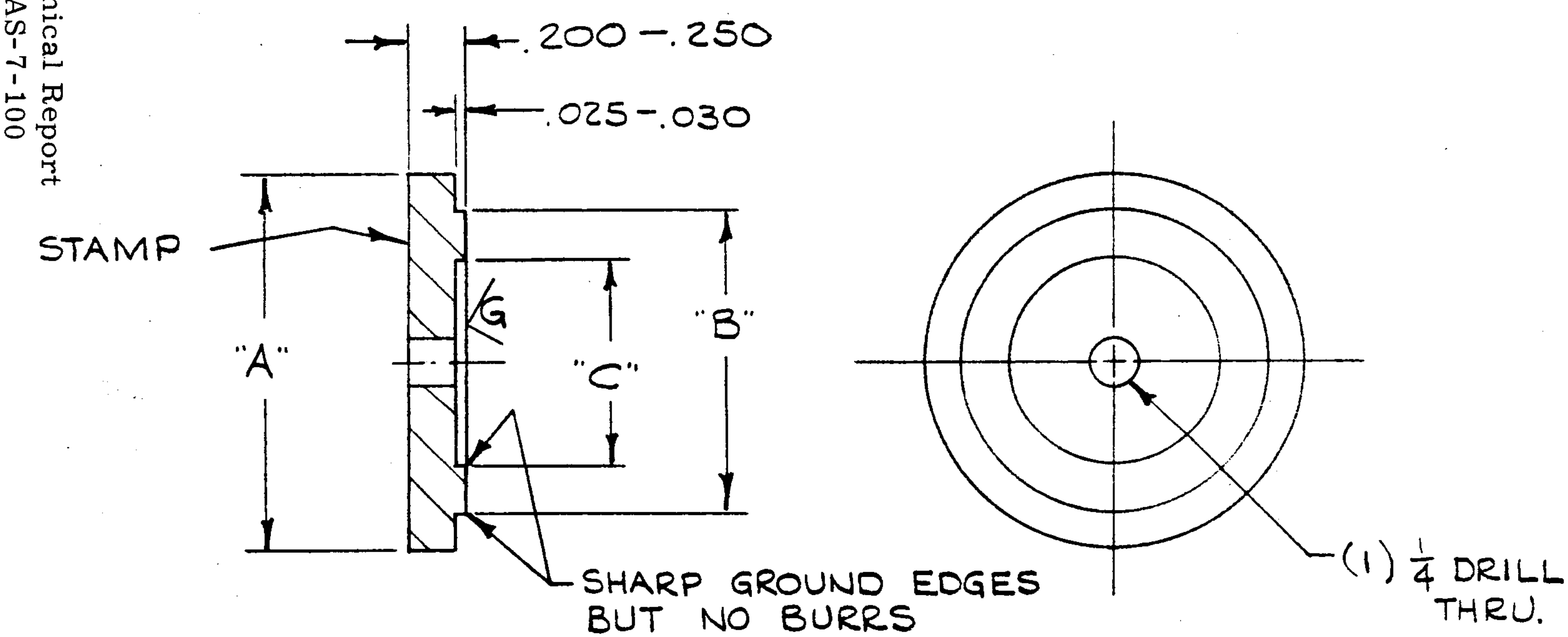
BASE - 14127



BRAZING BASE
14131



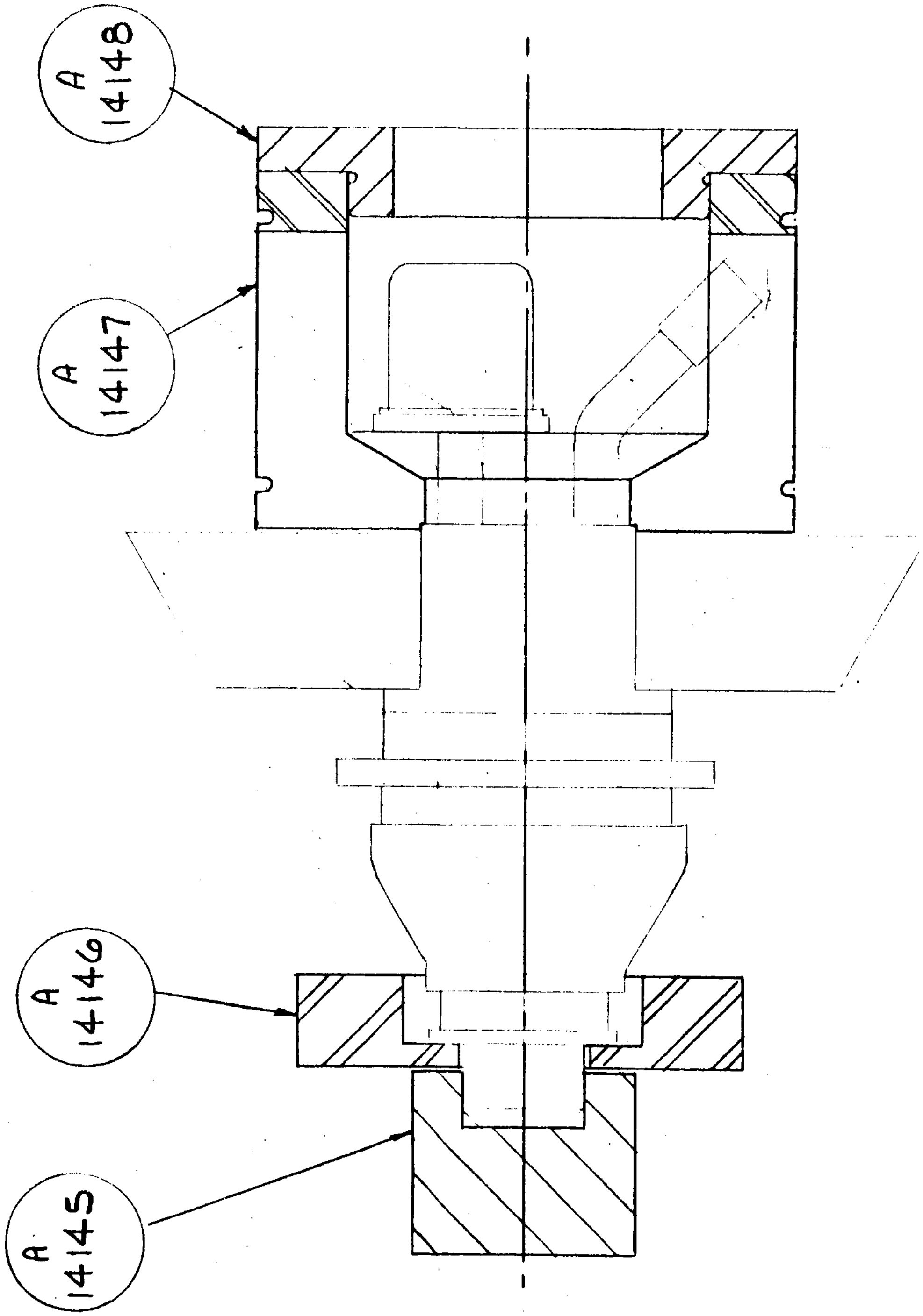
BRAZING JIG
14132



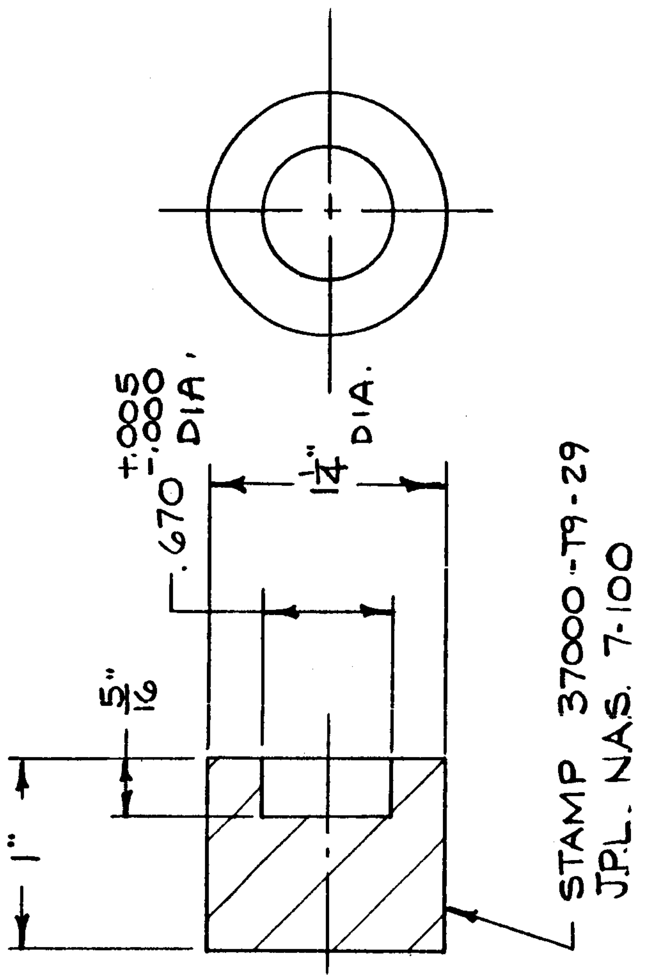
PT.	"A"	"B"	"C"	TOOL # STAMP	MATERIAL	
1	$2\frac{3}{8}$"	$2.100^{\pm.005}$	$1.355^{\pm.005}$	37000-T8-29-1	(1) PC. GA. ST. $\frac{1}{4}$" TK. X	$2\frac{1}{2}$" SQ.
2	$1\frac{7}{8}$"	$1.250^{\pm.005}$	$.800^{\pm.005}$	37000-T8-29-2	(1) PC. GA. ST. $\frac{1}{4}$" TK. X	2" SQ.

RUBBER DIE SOLDER WASHER

14143



BRAZING JIG
14144

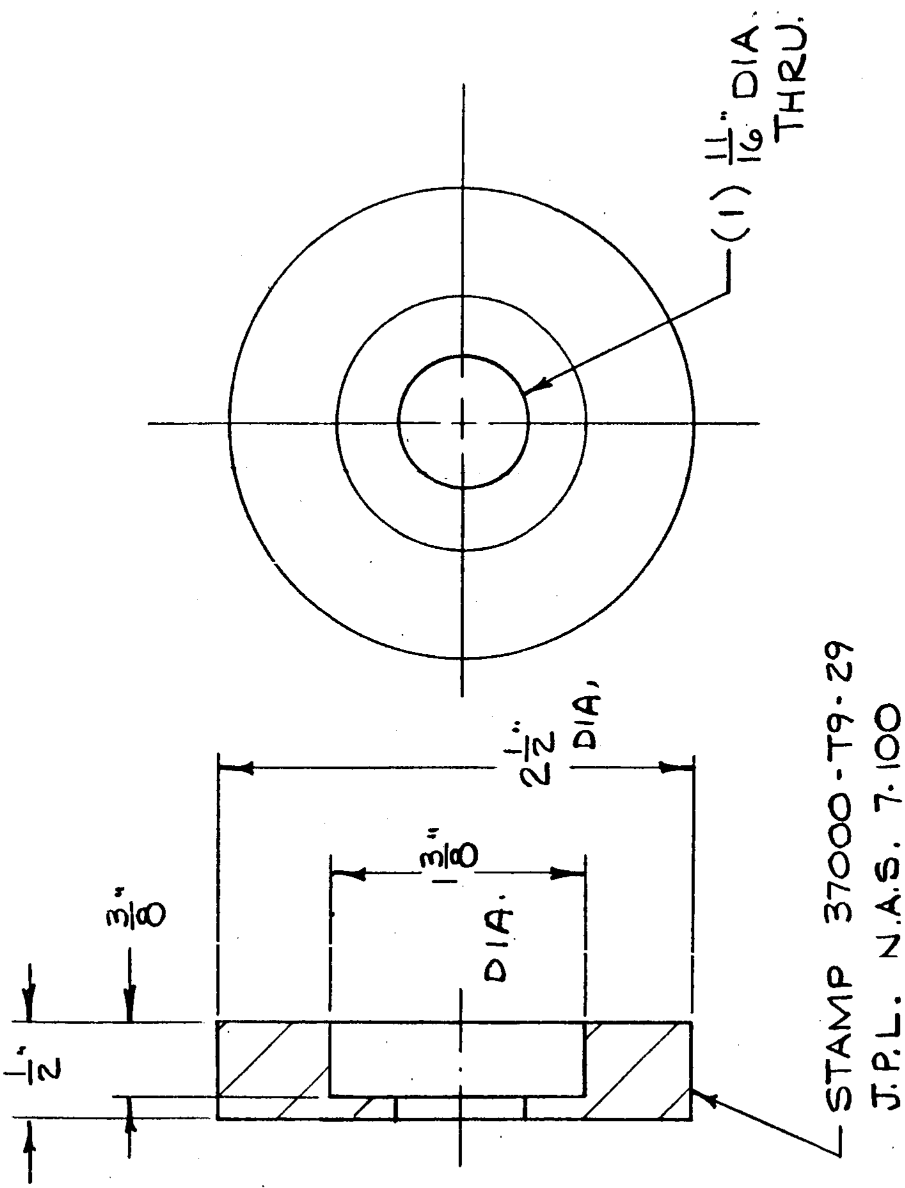


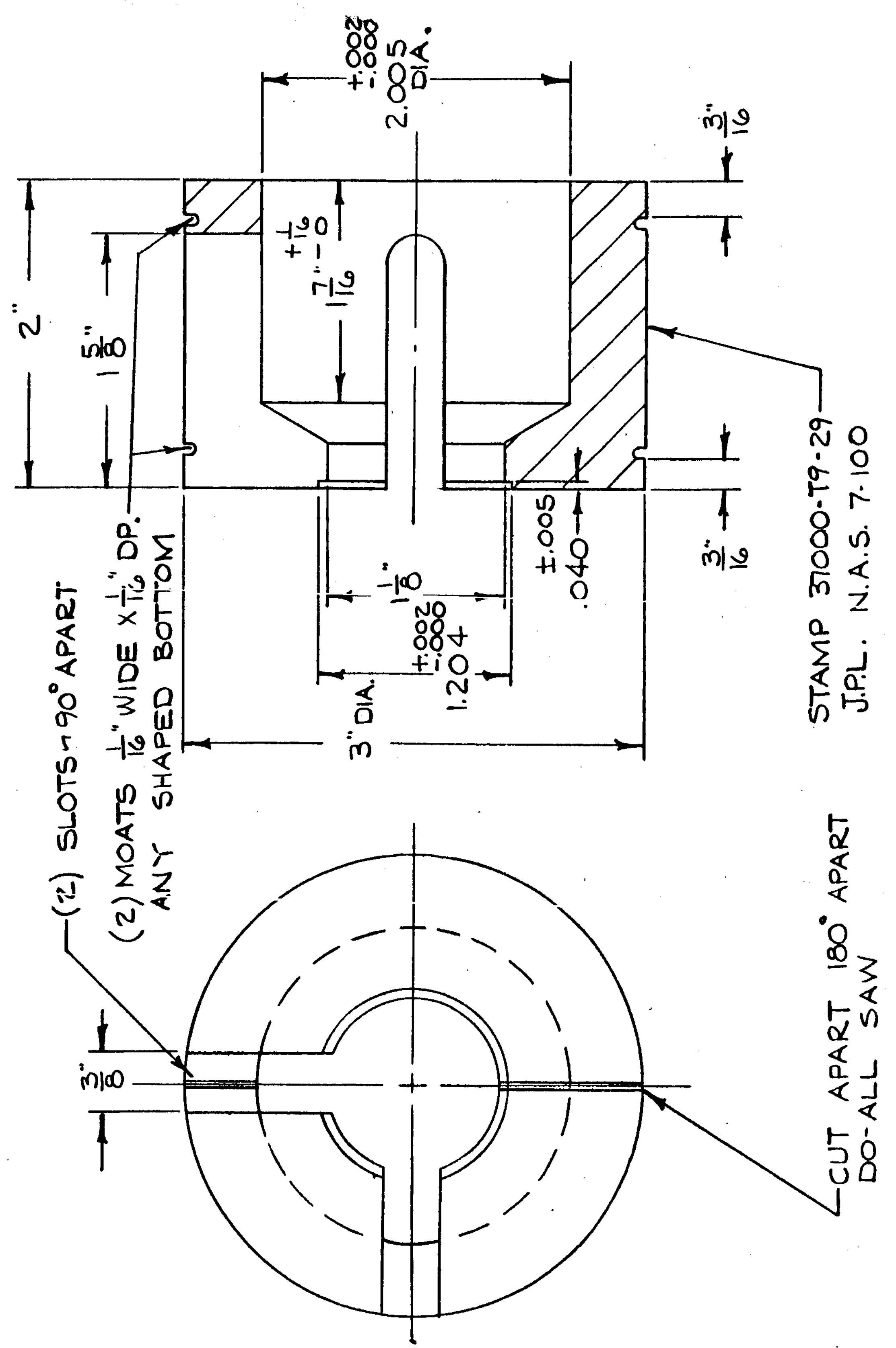
EMITTER WEIGHT

14145

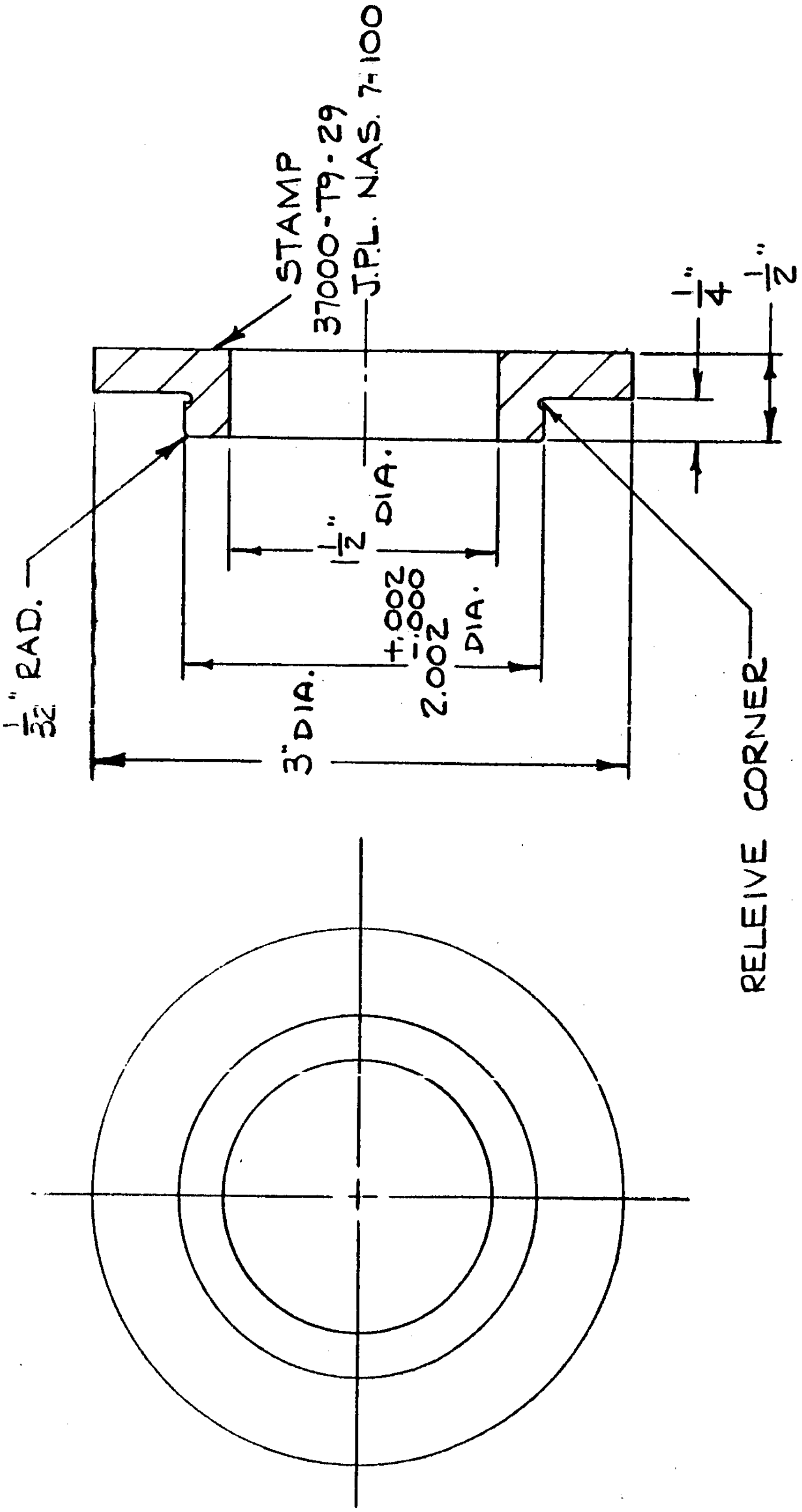
GENERATOR SUPPORT RING, WEIGHT

14146

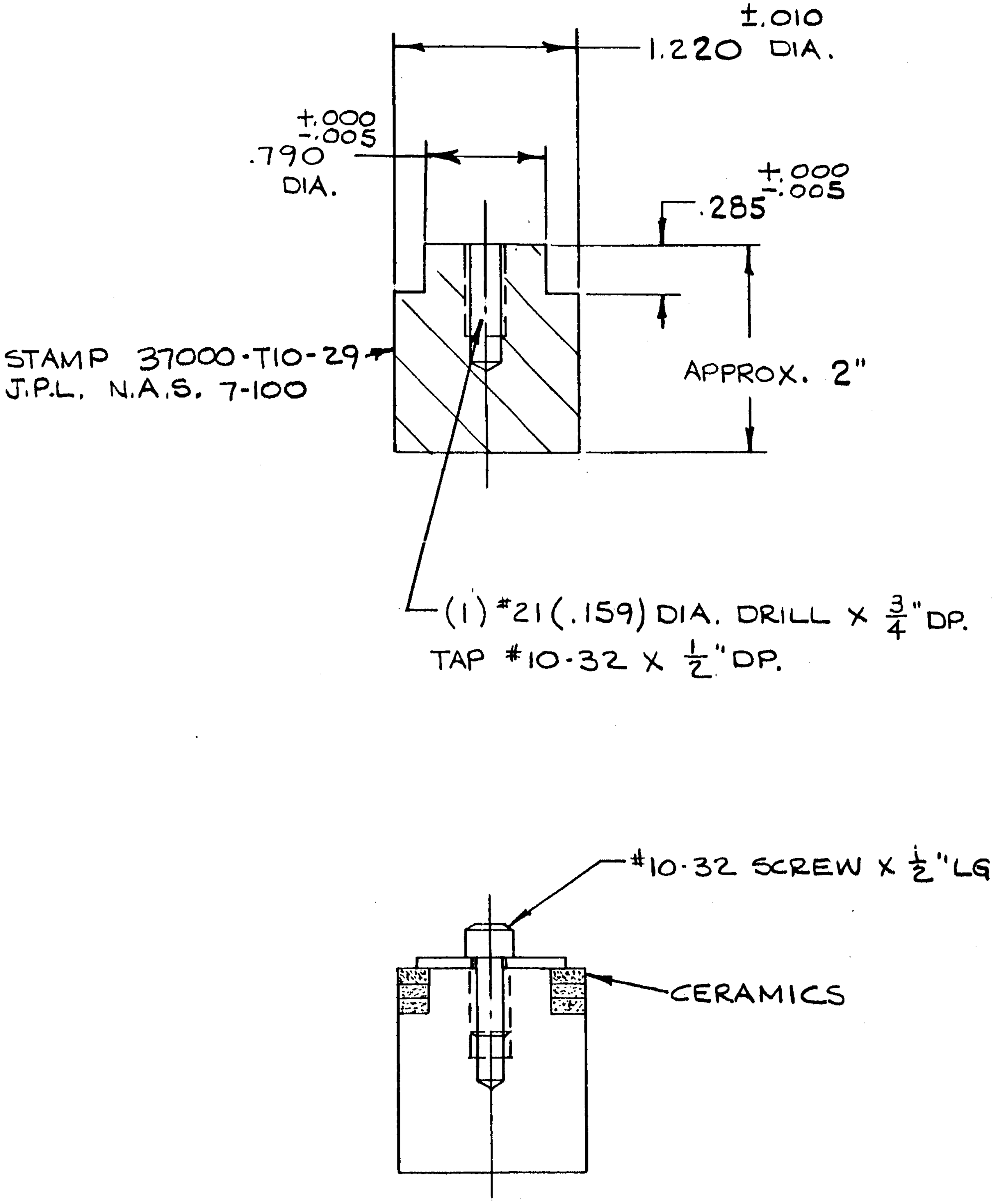




SPLIT RING
14147


STAMP
37000-T9-29
J.P.L. NAS. 7-100
1/4"
1/2"
1/32" RAD.
1 1/2" DIA.
+.002
-.000
2.002 DIA.
3" DIA.
RELEIVE CORNER

BASE
14148



GRINDING FIXTURE

14151